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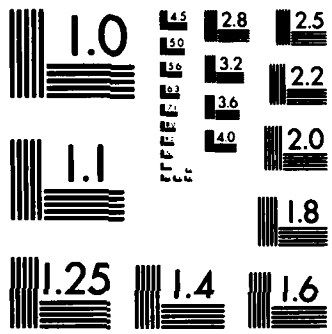

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FOREIGN TECHNOLOGY DIVISION

AIR FORCE SYSTEMS COMMAND

PLANNING OF COMBAT OPERATIONS AND COMMAND OF TROOPS
WITH THE AID OF NETWORK GRAPHS

by

P.G. Skachko, G.T. Volkov, V.M. Kulikov

FOREIGN TECHNOLOGY DIVISION

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By: P.G. Skachko, G.T. Volkov, V.M. Kulikov

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PREPARED BY:

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FOREIGN TECHNOLOGY DIVISION
WP-AFB, OHIO.

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U. S. BOARD ON GEOGRAPHIC NAMES TRANSLITERATION SYSTEM

Block	Italic	Transliteration	Block	Italic	Transliteration
А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*<u>ye</u> initially, after vowels, and after ъ, ь; <u>e</u> elsewhere.
When written as ё in Russian, transliterate as yё or ё.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

GRAPHICS DISCLAIMER

All figures, graphics, tables, equations, etc. merged into this translation were extracted from the best quality copy available.

Page 1.

PLANNING OF COMBAT OPERATIONS AND COMMAND OF TROOPS WITH THE AID OF NETWORK GRAPHS.

Under the general editorial staff of Colonel P. G. Skachko.

P. G. Skachko, G. T. Volkov, V. M. Kulikov

Page 2.

Planning combat operations and control of troops with the aid of network graphs. M., Voenizdat, 1968.

In book are opened essence systems of network planning and control, its advantage over existing system, shown its value in military affairs are given recommendations regarding use/application.

Basic concepts about system of network planning and control are presented, are described rules of formation of network graphs, order of calculation of their parameters, examples to optimization of nets/systems are given. After mastering basic principles, it is possible to independently construct the order of calculation and analysis of the nets/systems, presented in the book, and to calculate more complicated nets/systems.

This labor/work is first in military literature. It is designed for the officers and the Generals of all branches of service.

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PREFACE.

At present occurs rapid/vigorous process of equipping armed forces with weaponry and by combat materiel of new forms. As a result in military affairs basic changes occur. Therefore sharply increased volume and diversity of works both directly in the sphere of planning and conducting the combat training of the troops/forces and their combat activity and in the sphere of design and production of combat materiel. Communications/connections between different processes extremely were complicated, sharply increased the volume of the information, necessary for staffs/headquarters for the command of troops and, etc. At the same time the periods, during which the staffs/headquarters and others managers of echelon of command must accumulate information, analyze it and react/respond to the occurring changes in the situation, change or more precisely formulate the previously decisions/solutions accepted or make new decisions in accordance with the new situation, constantly they are reduced.

Existing methods of planning and management of processes, left to us as inheritance by time itself, no longer can completely ensure necessary operational efficiency and quality of control.

In military affairs contradiction between level of development of combat materiel and level of control of them appears. The development of means/facilities, forms and methods of the control lags on the rates/tempos behind the development of combat materiel and means of production. On the solution/resolution/permission of the contradiction mentioned above work many scientists and practice in our country and abroad. Their labor/work in a matter of finding the ways of the improvement of control led to the creation of new computer technology, different means of the mechanization of administrative labor/work, new communications and number/series of the new forms of the organization of the control. However, problem far is not solved. Searches continue.

Finding new, more effective methods of planning and management of different processes, connected with expenditures of human, temporary/time, material and other forms of resources/service lives, led to creation of new system of planning and control, which obtained abbreviated/reduced designation SPU[1] in our country.

FOOTNOTE [1]. SPU - system of network planning and control. ENDFOOTNOTE.

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This system of network planning and control in the short time found the widest application in the industry, with planning and realization of scientific works and design developments, in the building, during planning of training process in the educational institutions, and also in the sphere of the distribution of material resources.

This so wide and rapid a dissemination of this new method in our country and abroad is explained by its advantages over existing traditional methods of planning.

Its objectivity is one of most important advantages of method of network planning and control over existing methods. This method gives the capability to objectively establish/install minimally required time, and if necessary and the required flow rate of material resources for the accomplishment of one or the other objective and thus to exclude subjectivism and voluntarism in decision making. Commander (leader obtains the capability to make decisions on the basis of precise and substantiated calculations/crews, produced with the aid of the network graphs.

Experience/experiment/lesson shows that economic results, obtained from expenditures for improvement in control, in majority of

cases are considerably higher than economic results, obtained from expenditures for new technology. In this connection appearance and widespread putting into practice of the network method of the planning and management opens/discloses large prospects. Appeared the real capability to completely change the organization of the control of complex and large systems in all spheres of human activity, and, first of all, in military affairs. The creation of system; network planning and control is estimated as outstanding achievement in the region of the control in the latter/last 20 years.

Network method of planning and management finds widest application in our country. Use/application of method SPU during the building of such large/coarse units as the Lisichan chemical plant, Burshtyn GRES, giant automatic blooming machine in Chelyabinsk, and also during the building of metro bridge across r. Dnepr in Kiev, during the repair of open-hearth furnaces at the metallurgical plant "sickle and hammer" in Moscow and on other objectives, gave large payoff/gain in the time and in the means/facilities. This payoff/gain is obtained due to the best, scientifically substantiated organization of works on the base of network graphs.

Network method of planning and management, as first experiments showed, can successfully be utilized both during planning of combat training, combat readiness and combat operations of troops/forces and

during command of troops.

Widely can be used and is applied method of network planning and control also during building of military objectives, during creation of new weapon systems, when appears wide front of complicated complex works, for execution of which are drawn whole collectives of specialists, tens of different installations, large quantity of enterprises.

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Network graphs, their analysis and optimization make it possible in these cases to accurately coordinate the activity of numerous executors/performers in the time, and to also find the ways of the most rational organization of works in the minimally short periods with the smaller expenditures of supplies.

Thus, for instance, during development and creation in USA of system "Polaris" participated about 250 contractors and 6000 subcontractors, whose activity it was necessary to coordinate on time. The method of network planning and control, which is called in the USA "System PERT"[1], used with the creation of this rocket/missile, to a considerable degree contributed to the success of the execution of draft/design/project. Program "Polaris" was

carried out in three years instead of the initially planned/glide five years. The network method (its different modifications: "PERT-time", "PERT-cost/value", "PERT-reliability") in the armed forces of the USA used during the creation rockets/missiles "Nike Zeus" and other forms of complicated armament. At present not one industrial firm, not one military draft/design/project finance themselves by the Ministry of the Defense of the USA without the network model of the course of the execution of order.

Network graphs are applied also in military production of FRG, in particular, they are used for support/security/provision of rhythmicity of production of new West German tank "Leopard".

Besides aforesaid above about prospects of applying system SPU in military affairs, should be also noted capabilities of using this system in scientific research theoretical works, during forecasting of most probable conditions of combat situation in soldier with use/application of new combat materiel and especially during forecasting of probabilistic estimations/evaluations of time, necessary for execution of one or the other particular problems (works), during definition/determination of probable rates of advance (rates/tempos of march), expenditures of material resources, etc.

Utilizing method SPU, it is possible to lighten scientifically

substantiated searches for most rational methods and forms of organization of battle and operation/process in modern war.

Existing/available experience/experiment/lesson and practical results of applying network graphs in military affairs, and also conducted investigations on this question in military academy of armored forces make it possible to draw conclusion that network methods of planning and management have large future in military affairs. They successfully can be used for planning of combat operations and command of troops in all echelons of command.

FOOTNOTE. [1]. PERT - in abbreviated form from words Program Evaluation and Review Technique (of survey/coverage and estimation/evaluation technique of program). ENDFOOTNOTE.

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First of all they will give large effect during decision/solution of tactical questions, especially at stage of planning and organizing combat operations of troops/forces, with organization and realization of complicated processes of combat, engineering, material and technical support of troops/forces, while planning and conducting of mobilization measures and inclining troops/forces for battle alarm/alert. They can give also large effect

with planning of the combat training for the troops/forces and training process in the troops/forces and educational institutions.

Network graphs finally offer new possibilities of improving methods of assembly of information and of its rapid processing with the aid of electronic computers (computer(s)), capabilities of using codes of works used in network models in interests of concealed/latent command of troops.

However, it is necessary to keep in mind that all capabilities indicated above of applying network method of planning and management in military affairs can be realized only when officers master well this method.

This book is one of first in military literature works, dedicated to network methods of planning and management. It pursues the target to present basic concepts about the system of network planning and control and its elements/components, the rule of scheduling network, the order of calculation of the parameters of nets/systems and their optimization in connection with the requirements of planning the activities of the troops/forces and control of them in combat. Work also pursues the target based on the simplest examples from the practice of military affairs to show the capability of applying the network method of planning and management

and its value in a matter of the improvement of the methods of planning the activities of the troops/forces and control of them, improvement of forms and methods of organizing of combat training, repairing of combat materiel, scientific research and designing in the armed forces, in a matter of the support/security/provision of high combat efficiency and constant combat readiness of the army and navy.

Authors of labor/work fully and in available form opened essence of network method of planning and management, showed advantages, capabilities and principles of its use/application in military affairs generally, also, during planning of combat operations and command of troops in particular.

Proposed to reader labor/work based on examples consistently opens procedure of compilation of network graphs, their optimization, order/formation of use of results of analysis of these graphs/curves in matter of improvement in planning activities and command of troops and therefore successfully can be used for independent study of network method of planning and management and as allowance during practical use/application of network graphs by officers in troops/forces.

Work is designed for officers, students of military academies and cadets of military schools.

Doctor of military sciences, professor Lt.-General of tank forces G. Zavizion.

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Chapter 1.

GENERAL CONCEPTS AND ELEMENTS OF THE SYSTEM OF NETWORK PLANNING AND CONTROL. Order of compilation of network graphs.

1. General concepts about method.

§1. Characteristic of the network method of planning and management.

At present in national economy rapid/vigorous formation of new sector/direction in organization of control of complicated processes, connected with flow rate of human, material, energy and other resources, occurs. Among the most important new forms and the methods of the improvement of control the widest use obtains network method. The successes and the rapid dissemination of this method literally are almost in all spheres of human activity stipulated/agreed upon/caused, first of all, by its great advantages in comparison with the existing methods of the plannings, at basis of which lie/rest strip/tape or linear graphs/curves.

These advantages consist of following.

1. Use/application of network method of planning and management on base of best, logically and mathematically substantiated organization of work, as showed practice, gives considerable savings of forces, means/facilities and time, provides planning and control of complicated developments [1] simultaneously for several sectors/directions, it makes it possible to eliminate from field of intensive control those works, which do not affect timely accomplishment of objective as a whole, to find bottlenecks and to in a timely manner overcome them.

In military affairs use/application of network method of planning and management also gives capability due to maneuver by available of command of forces and of means/facilities, conducted on basis of precise calculations/crews, to gain time and to achieve greater results than during planning and management of conventional/ordinary methods.

2. Network graphs provide demonstrative and convenient for perception image of plan/layout, developed both as a whole, and in parts.

FOOTNOTE. [1]. By development (draft/design/project) in network method

of planning and management (SPU) is understood specific, preestablished complex of all operations/processes, they are which necessary to fulfill for achievement of intended target. By this term we will also understand planning any combat operations in all echelons of command. ENDFOOTNOTE.

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They allow more substantiated, taking into account actual position of affairs, to reexamine the decisions/solutions accepted, to obtain predictions/forecasts of the future, to foresee possible deflections from the plan/layout and their consequences, which can influence the final periods of its execution. Network graphs will make it possible to quantitatively measure the measure of uncertainty, inherent in each plan/layout. The system of network planning and control makes it possible to widely and efficiently apply electronic calculating engineering.

3. Network method of planning and management at stage of planning during use of network graphs as model of development makes it possible to clearly reflect/represent volume of decided problem; to reveal/detect with any degree of elaboration of work, entering development; to establish/install interconnection between these works; to determine events, whose accomplishment is necessary for

achievement of particular and final goals presented; it is clear to distribute responsibilities between co-executors of works; to eliminate passage of works, objectively necessary for achievement targets of development.

4. Network method of planning and management makes it possible: to more widely utilize during planning experience of most competent and prepared executors/performers of works, and also checked in practice statistical data for the purpose of most real estimation/evaluation of requirements for forces and means/facilities, necessary for execution of works; in advance, in analysis run of model of development, to find concealed/latent reserves and to plan routes/paths of their use and, in particular, method of using resources/service lives of noncritical works, guiding them to acceleration of critical works how to strive execution of entire development within shorter periods and with smaller expenditures of human and material resources.

5. Network method of planning and management makes it possible to apply simple procedure of introduction of changes, refinements and supplements into plans/layouts of developments, which leads to flexibility of planning and its continuity, provides simplification in information and system of account, and also rapid inclusion into work of new persons of administrative staff and continuous control

upon shift/relief of leaders of development. During the use/application of electronic computers the network method of the planning and management provides counting/reckoning/error in the short time of a large number of versions of job schedule, from which is driven out/selected optimum.

Thus, network method of planning and management makes it possible to obtain scientifically substantiated responses/answers to most important questions, which appear during planning and coordination of many interdependent/interconnected developments.

At conclusion of general/common/total characteristic of network method of planning and management it is necessary to note that it can be used without depending on scale and complexity of development. Greatest effect the network method of the planning and management gives in the complicated developments, in the complex dynamic guided systems, where the widest possible application of electronic computers.

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But at the same time the network method of the planning and management gives considerable positive effect, also, with the realization of the developments of very small scale, which

include/switch on a total of several ten events. Thus, for instance, it is used with development and analysis of individual tactical decisions/solutions, during the development not only of the entire system of the measures of the combat readiness of the troops/forces, but also its individual elements/components.

S2. Division of the system of network planning and control.

Network method of planning and management has direct relation/ratio to cybernetics as science about optimal control of complex dynamic systems.

It is known that any control both in national economy and in military affairs assumes presence:

- objective of control (guided system);

- environment (situation conditions);

- system or construction, that affect objective of control (controlling system).

As objective of control there can be vehicle/computer and people.

Most characteristic objectives of control under contemporary conditions become objectives with considerable quantity of participating in operation/process (development) collectives and with large number of works, i.e., complex dynamic guided systems. The complexity of the guided system is characterized by a quantity of elements/components, by character and strength of communications/connections between them, and also by number of different conditions, in which can be located the system. The dynamicity of system becomes apparent in the constant shift/relief of conditions, of environment, and also a change in the parameters.

By environment (situation conditions) should be understood external influences/pressures on objective of control, condition, in which is located and will be located guided system in process of achieving intended target. If we speak about the troops/forces, then external (ambient) medium for them is the concrete/specific/actual situation, in which they perform, i.e., the degree of the influence/pressure of enemy, condition of terrain and time of the year, weather, material and technical support, etc. With a change in the external influences/pressures the parameters of system change, in consequence of which reaching/achievement of the final goal hinders or is facilitated.

By manager system is understood command agency (staff/headquarters, installation, factory management, etc.), which has respectively branched net/system of subordinates of command agencies (staffs/headquarters, installations, shops, sectors) or individual executors/performers (commanders).

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In other words, this is the branched administrative (administrative) apparatus, which disposes of requisite resources and armament for the realization of control functions of development (operations of the troops/forces, designing or production process). Moreover controlling system in accordance with the principles of contemporary cybernetics for the support/security/provision of a control process must possess the same branching as the guided system. The effectiveness of the activity of the manager of system first of all depends on the quality of the work of the service of information.

Conducted investigations of control process in our country and abroad shows that about 40% of time of leader and his apparatus are expended/consumed on obtaining, study and information analysis, 12% of time - to decision making, 30% - to return instruction and

instruction, bringing/finishing problems to executors/performers and 18% - for inspection/check of performance.

Thus, in control assembly of information and its processing occupy greatest time. This circumstance/case/fact exerted influence on the classification and division of the control systems.

As practice showed, managers of system can be classified according to purpose/designation, parameters of control, technical level and according to types of models. This division occurs, also, in the system of network planning and control.

According to purpose/designation managers of system of network planning and control are divided into special-purpose ones and multipurpose ones. Special-purpose system is characterized by the complex of the activities, directed toward achieving of one specific goal, although in this complex of activities can take part many individual executors/performers or subunits, target in them one, for example, to ensure the high combat readiness of subunit, to in a timely manner plan and to conduct battalion exercise, etc.

Multipurpose system is applied if necessary to control/guide activity of number/series of subunits (units) of different branches of service, that pursue different targets in single complex of

problems.

From parameters controls of system of network planning and control are divided into systems, as basis of which are taken individually (parameter of time) or in combination these or other parameters: time, cost/value, resources/service lives, technical and economic indices/measures.

Parameter of time is considered in all cases.

Depending on combination of different parameters it is possible to name/call following eight varieties of control systems:

1) SPU - time;

2) SPU - time-cost/value;

3) SPU - time-resources/service lives;

4) SPU - time-technical-economic indices/measures;

5) SPU - time-cost-resources/service lives;

6) SPU - time-cost-technical-economic indices/measures;

7) SPU - time-resource-technical-economic indices/measures;

8) SPU - time-cost-resource-technical-economic indices/measures.

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In practice widest use received systems of SPU with parameter of time.

On technical level all systems SPU can be described as machine systems, based on wide application of different means of mechanization, computer technology, communications, television.

Are distinguished five levels of system of control SPU.

1). Zero, which is characterized by the use/application only of simplest means of the mechanization of administrative labor/work, simplest computer technology. At this level of the system of control in the broad sense there is no this word.

2). The first level - this is already qualitative jump in the development of the system of planning and control, although outwardly

this level differs little from the zero level in the scales of the use/application of means/facilities of mechanization and computer technology.

First level is characterized by regular entrance of input data and by their processing on established/installed program, regular use by leadership/manual of output information, uniformity of input and output information, as a rule, only from one parameter.

3). The second level is characterized by the use of powerful/thick electronic computers with the developed systems of the machine memory. In the controlling systems of the second level the information from the diverse parameters is utilized.

4). The third level is characterized by the creation of the special integrated systems with the modeling, and also with the training session of leaders. This level of the control systems is characterized by the extremely high quality of the work of the service of information.

5). The fourth level is the development of the systems of the third level. The managers of the system of the fourth level provide modeling, playback of process, training session of leaders and automation of the unit of the process of decision making.

According to types of models of control system are divided into systems, which use linear models, and systems, which use network models. Moreover by model here should be understood the plan/layout of development, comprised in such a way, that it wave would reflect entire course of events on reaching/achievement of the stated goal under the given conditions.

Graphic methods of modeling are most widely used in practice. They are more multi-purpose and forseeable. Widely can be used the graphic methods of modeling (planning), also, in the practical activity of the troops/forces.

Examples of this modeling are different schedules of measures, plans/layouts of combat training, plans/layouts of conducting exercises and other documents, fulfilled on maps/charts/cards or in the form of diagrams/plans/circuits and graphs/curves with necessary explanatory notes.

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The variety of the graphic modeling of combat operations, cooperation used for the organization, training of officers and for other

targets, is modeling possible combat situation on the sand tables.

In the past, before appearance of network graphs, they were extended and are applied at present different varieties of linear graphs/curves and cyclograms (Fig. 1).

However, together with positive sides of linear graphs/curves and cyclograms (demonstrative expression of assigned missions, sequence/consistency and periods of their execution) they have serious deficiencies/lacks.

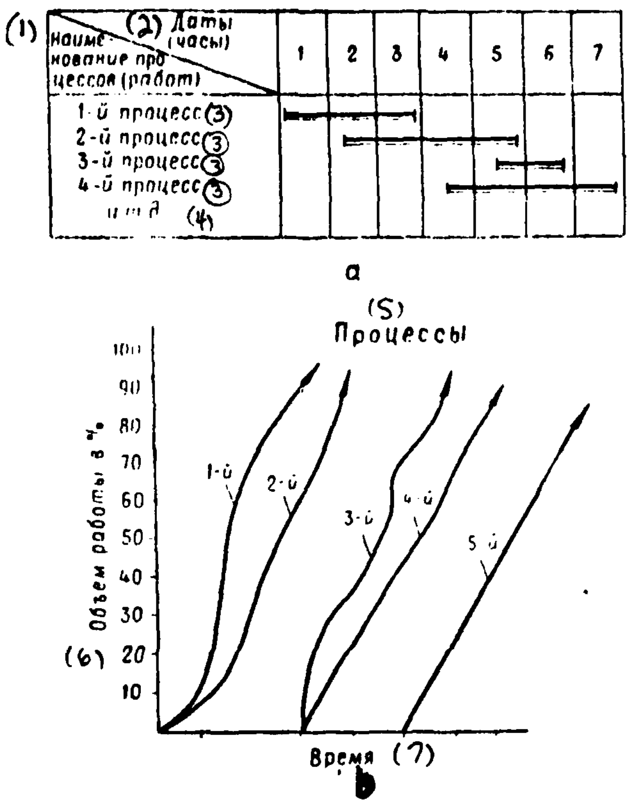

Fig. 1. Graphs/curves: a) linear; b) cyclogram.

Key: (1). the designation of processes (works). (2). Dates (hours). (3). process. (4). and so forth. (5). Processes. (6). Volume of work in %. (7). Time.

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Basic of them are:

- insufficient reflection/repulse of communications/connections between the processes and the works and their interdependence;

- especially static approach to their compilation, since the decisions/solutions placed in them take the thickening form; graph/curve is broken away and it becomes unreal;

- limited capabilities of forecasting and control of the course of the execution of development;

- *personnel/staff/composition of works and the periods of their* execution are designated unambiguously, which unavoidably leads subsequently to the correction of the model of plan/layout, and this on the linear graphs/curves to make is very difficult;

- linear models do not reflect that uncertainty, which is inherent in processes and development as a whole.

Therefore appeared need for creating such model, which would make it possible with large effect to realize planning, control, adjustment of plan/layout, management and to extensively use electronic computers.

Such requirements completely answer network graphs and system of network planning and control, advantages and advantages of which were discussed above. However, here one should emphasize that the network graphs, providing the high objectivity of planning and forecasting the course of the execution of development, and also large operational efficiency and the effectiveness of leadership/manual, do not eliminate use/application in the control of linear graphs/curves, cyclograms and by the fact of the graphic plans/layouts of the combat operations of the troops/forces, developed/processed on the maps/charts/cards or the diagrams/plans/circuits.

2. Bases of the formation of network models.

As basis of system of network planning and control is assumed graphic representation of plan/layout of development in the form of arrow logical diagram (network graph), in which entire complex of operations/processes is developed/extended to individual, clearly specific works. In this case network graph reflects/represents logical interconnection and interconditionality of all works and the sequence/consistency of their execution from the beginning also to the final goal of development.

§3. Elements/components of network graphs.

Let us examine basic concepts, definitions/determinations and terms, necessary during mastery of network method of planning and management.

During scheduling of network they proceed of three basic concepts: "work", "event", "route/path".

Work - is any labor process or activity, which is accompanied/tracked by expenditures of time and resources/service lives. For example, loading ammunition on battle alarm/alert on the army depot/dump, the march of the troops/forces into the concentration area on the alert/alarm, etc.

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Into concept "work" enters also waiting (passive process), to that it is necessary to spend neither labor/work and nor resources/service lives. For example, halts or night rest of personnel during the completion of march, the waiting of the sequence of the crossing through the water obstacle on the ferries or on the bridge according to the schedule of crossing, etc.

By "work" is implied also simple dependence between two or large number of measures (processes). This there will be the fictitious, or no-load operation, to which also it is not necessary to spend time.

Operating time, as any process, it can be measured quantitatively in units of time: minutes, hours, days, etc. In work can be also other quantitative evaluations, for example labor expense, cost/value, the expenditure of material resources, etc. Furthermore, each work must have a definition, which opens its content, for example "understanding of problem", the "estimate of situation", the "warning of subunits according to the alert/alarm", "loading of ammunition on the alert/alarm", etc.

Event - sum of one or the other process, intermediate either final result of execution of one or several previous works, which makes it possible to begin realization of subsequent works. For example, assembly and shaping of the columns of subunits on battle alarm/alert in the points/posts of constant deployment are completed, which makes it possible to begin their movement into the assigned concentration area

Thus, event in contrast to work is not process, it does not have duration, it is accompanied/tracked by no expenditures (time, resources/service lives).

Event on network graphs is usually depicted as small circles, work - by continuous arrows, and no-load operation (dependence) - by broken pointers (Fig. 2).

Pointers are not vectors. Their length and sectors/directions can be arbitrary.

Any work (arrow/pointer) of network graph connects only two events and represents process of transition/transfer from one event to another.

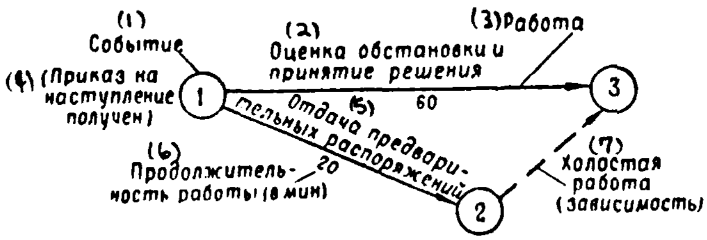

Fig. 2. Image of events and works on the network graph.

Key: (1). Event. (2). Estimate of situation and decision making. (3). Work. (4). (Attack order it is obtained). (5). Recoil of warning orders. (6). Duration of operation (in min). (7). No-load operation (dependence).

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The event, from which the arrows/pointers emerge, is called initial (or preceding); the event, into which the arrows/pointers enter, final (or following) for the given works. One and the same event can alternately to be previous and subsequent. Initial event for the entire net/system is called initial, and the final event of entire net/system - completing.

Works in net/system are usually coded by numbers of events, between which they are included. For example, work "understanding of problem" (Fig. 3) will have code (1, 2), and work "timing" can obtain

code (2, 3).

In Fig. 3 event (2) is subsequent for work (1, 2) and preceding for work (2, 3).

Into one and the same event can enter several works or only one work, and from it to emerge also only one or several works. Therefore the accomplishment of event can depend on completion with respect one or several works.

From Fig. 4 it is evident that works (d and e) can be begun only in such a case, when execution of works (a, b and c) will be completed.

All works of graph/curve are different by nature and have different duration.

Thus, event is considered completed only if quite prolonged of all entering it works will be completed.

Internal interconnection between works in graph/curve is determined by observance of fundamental rule: in network graph all works are interlocked - beginning of subsequent work is stipulated/agreed upon/caused by termination of preceding/previous.

From this rule it follows that in the graph/curve there cannot be one works, not connected with their beginning and termination with other works through the events. In other words, in the network graph there cannot be the events, whose offensive would not indicate termination, at least, one work and simultaneously the beginning of another.

Events are exception initial and completing. Initial event does not have the previous work and is initial for the entire development (for example, the "march order it is obtained", "signal to the incline of unit on battle alarm/alert it is obtained"), but that completing indicates the completion of entire complex of the measures of the development ("regiment to the execution of combat task/mission it is ready").

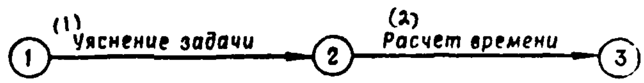

Fig. 3. Coding works by events.

Key: (1). Understanding problem. (2). Timing.

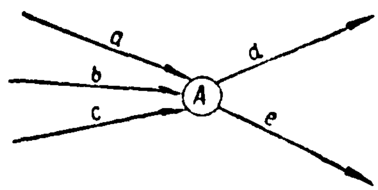

Fig. 4. Dependence of works.

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Each work, included in graph/curve, must have completely concrete/specific/actual content. It is not possible, for example, to define work as "beginning of loading ammunition" or the "termination of the formulation of the problems to subunits", since are here possible subjective representations about the concepts "beginning" and "termination".

In certain cases execution of unit of any work is condition for beginning of one or several other works. In this case the work can be broken into two or several independent sectors, concretely/specifically/actually determined on the time

(resources/service lives). In this case each sector of the shared work should be examined ~~KVK~~ as independent work.

It is so/such important to accurately formulate definition of events. It is incorrect, for example, to determine event "to finish the estimate of situation". This event must have a definition/determination the "estimate of situation is completed". A precise formulation of events concentrates attention of the originators of graph/curve and the persons, who realize the control and direction of development not only on what works must be carried out for achievement of the final goal of development, but also on that, such as must be the result of each work or group of the works, which precede one or the other event, in what concrete/specific/actual form work (works) it must be completed, so that the work following after it could be begun.

In network graph must not be locked ducts/contours, i.e., circular (circular) interconnections, since this interconnection can be logically absurd. For example, the interconnection of works shown in Fig. 5 cannot be in the practice, since the estimate of situation, carried out after timing, cannot precede understanding problem.

Route/path - this is any continuous logical (technological) sequence/consistency of works (chain/circuit of works) from initial

(first) event to that completing, i.e., from beginning of development of plan/layout to final goal. Here it is necessary to keep in mind that not one route/path can pass twice through one and the same event; any route/path can pass from the no-load operation; several routes/paths can pass through one and the same event.

Path length is determined by sum of duration of operations lying/horizontal on it. From the initial event to that completing there can be many routes/paths.

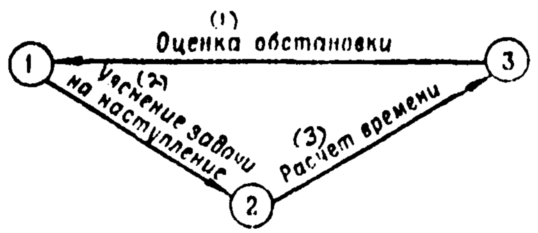

Fig. 5. Locked duct/contour.

Key: (1). Estimate of situation. (2). Understanding problem to offensive. (3). Timing.

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As a result of compilation and analysis of network graph is revealed/detected such route/path, the total operating time on which will be maximum. This route/path is called critical. Specifically, it determines the necessary time of the execution of all works, connected with the network graph.

All works, which lie on critical path, are also critical works. On the duration of these operations the duration of critical path depends. The reduction of critical works or an increase in the life respectively will lead to increase or reduction of route/path. Thus, all critical works are the potentially bottleneck of plan/layout.

In net/system it is possible to find several critical paths. Routes/paths, close ones in the time to the critical ones, call subcritical. All remaining routes/paths, and them there will be majority, considerably they differ in the duration from the critical and subcritical paths to the smaller side. Such routes/paths are called the non-critical (or noncritical) paths.

Works, which lie on critical path, are emitted by heavy lines or dual (colored) line as this shown in Fig. 6. Isolation/liberation on the schedule of operations, which are located on critical path, gives the capability in the demonstrative form to represent that sequence/consistency of works, which determines the general/common/total periods of the accomplishment of objective. Especially this is important during the analysis of the complicated plans/layouts, in realization of which participates a large quantity of executors/performers.

On graph/curve (Fig. 7), which reflects complex of basic measures for preparation of subunit for offensive, it is possible to find six total/full/complete routes/paths. In order to determine, which of these routes/paths is critical, it is necessary to compare their duration:

$L_1 = (0, 1, 3, 7, 9)$; $t(L_1) = (5 + 5 + 60 + 20) = 90$ мин (1);

$L_2 = (0, 1, 3, 5, 7, 9)$; $t(L_2) = (5 + 5 + 0 + 60 + 20) = 90$ мин (1);

$L_3 = (0, 1, 2, 5, 7, 9)$; $t(L_3) = (5 + 15 + 60 + 60 + 20) = 160$ мин (1);

$L_4 = (0, 1, 2, 6, 8, 9)$; $t(L_4) = (5 + 15 + 15 + 30 + 15) = 80$ мин (1);

$L_5 = (0, 1, 4, 6, 8, 9)$; $t(L_5) = (5 + 5 + 0 + 30 + 15) = 55$ мин (1),

$L_6 = (0, 1, 4, 8, 9)$; $t(L_6) = (5 + 5 + 30 + 15) = 55$ мин (1).

Key: (1). min.

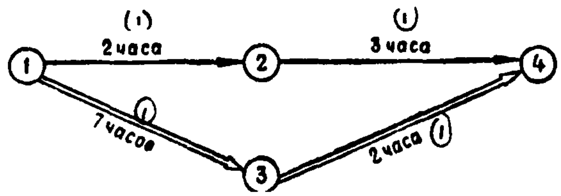

Fig. 6. Image of critical path (route/path 1, 3 and 4 - critical).

Key: (1). hours.

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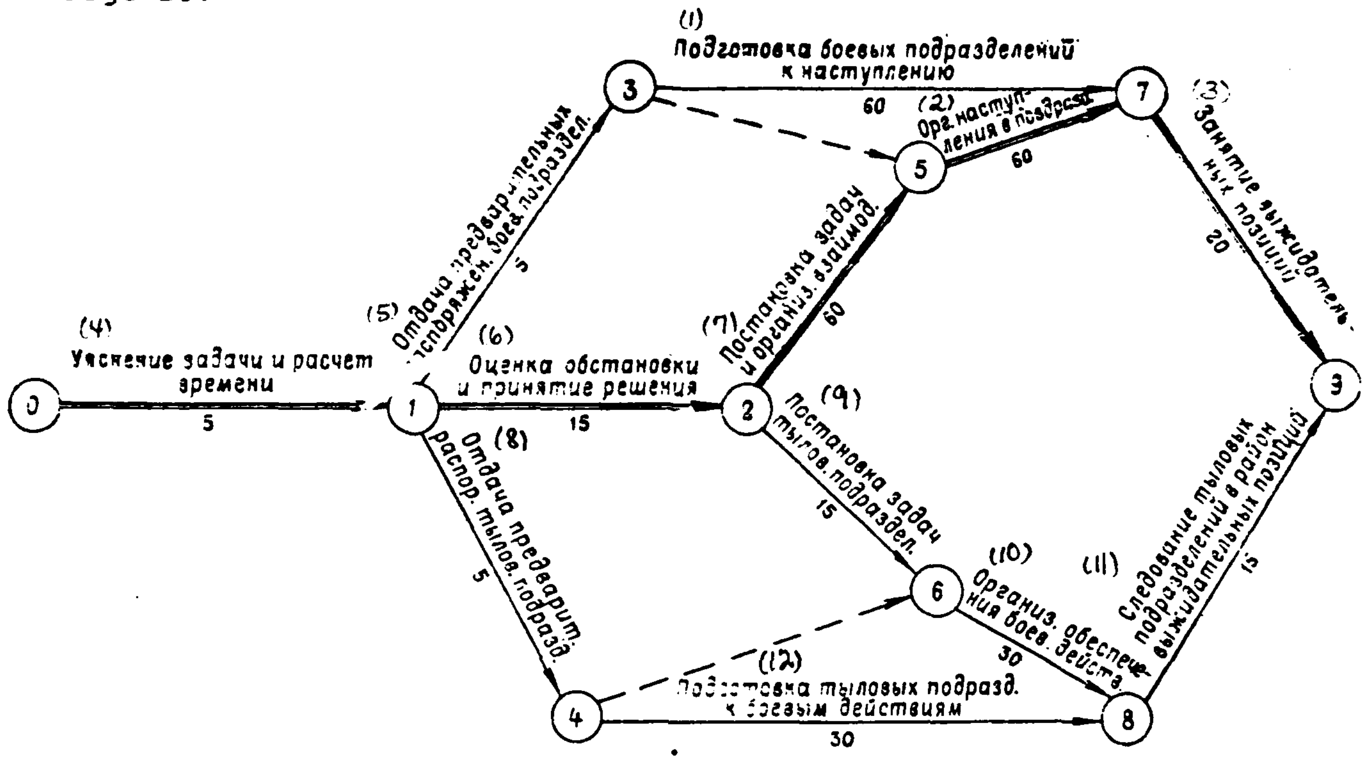

Fig. 7. Routes/paths in network graph.

Key: (1). Preparation of combat subdivisions for the offensive. (2). Org of offensive in subdivision. (3). Taking of expectant positions. (4). Understanding problem and timing. (5). Issue of preliminary orders to combat subsection. (6). Estimate of situation and decision making. (7). Formulation of problems and organization of cooperation. (8). Issue of preliminary orders to rear subdiv. (9). Formulation of problems of rear subsection. (10). Organization of support/security/provision of combat actions. (11). Sequence of rear

subunits into area of expectant positions. (12). Preparation of rear subdiv. for combat activities.

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From obtained routes/paths 3rd path quite prolonged, it will be critical path. Subcritical routes/paths they are respectively the 1st and 2nd path. The remaining routes/paths of this network graph will be unstressed (noncritical).

Besides total/full/complete routes/paths in network graph still following are distinguished:

- *route/path*, which precedes or which follows after given event; moreover route/path from initial event to this event is called previous, and route/path, which connects this event with terminal event, by route/path, which follows after given event;

- route/path between any two events on graph/curve, of which none is neither initial nor completing.

For example, on graph/curve (Fig. 7) for event (2) previous will be route/path (0, 1, 2); subsequent for this event will be routes/paths (2, 5, 7, 9) and (2, 6, 8, 9). The routes/paths between two events, for example by events (1 and 5), are routes/paths (1, 3, 5) and (1, 2, 5).

Any noncritical route/path has reserve of time, which is equal to difference between duration of critical path and duration of noncritical route/path. The works, which lie not on critical path, also possess the reserve of time, i.e., they allow/assume shifts/shears within the periods of their execution.

Presence of reserves of time in noncritical works gives capability to freely maneuver with internal resources/service lives due to increase in time of execution of some noncritical works (in limits of reserve of time) and with this to accelerate execution of critical and subcritical works. This exactly is the main thing in the network method of the planning and management.

In Fig. 7 we took simple net/system, in which it is simple to find critical and subcritical paths. For the more complicated nets/systems with a large quantity of events the miscounting employing procedure specially developed for this is required. Small nets/systems (graphs/curves) before 150-200 events usually cheat in counting by hand. Nets/systems with a quantity of events from 200 to 1000 and more, as a rule, they cheat in counting in the electronic computers. However, it is necessary to keep in mind that the large nets/systems (more than 1000 events) are difficultly visible. In

connection with this in the large/coarse developments it is expedient to compose several network graphs.

During scheduling of network it should be avoided increase in blank communications/connections (works). Should be introduced them into the net/system only in such a case, when they are actually/really unavoidable.

Elaboration of network graph is determined by volume and complexity of development, by capability of computer, and also structure (level) of leadership/manual. The higher the level of leadership/manual, the less the details in the net/system (each arrow/pointer - this the specific volume of works from several minutes to days and months).

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For development with number of events to 200 there usually is one common network graph.

During planning of large-scale operations/processes, in execution of which participate many executors/performers, are comprised several nets/systems. In such cases three degrees of the elaboration of nets/systems can be usually.

Nets/systems of first degree of elaboration are developed/processed coarsely for developing of general/common/total structure and operation - this of net/system for higher level of leadership/manual (compound nets/systems). In such nets/systems of work (arrow/pointer) the whole complexes of measures on the large/coarse scale reflect/represent.

Nets/systems of second degree of elaboration are comprised for middle link of leadership/manual. Such nets/systems - these are the particular or local nets/systems, which are developed/processed in more detail, although in them each arrow/pointer can

reflect/represent several works (complex of works). Primary network graphs are intended for the lowest level of leadership/manual. These graphs/curves can be detailed to the level, determined by the boundaries of the responsibility of executors/performers (for example, works, which are found in the conduct of one executor/performer). Primary networks count a larger number of events.

Detailed nets/systems because of need for repelling large number of interconnections and dependences in them have considerably larger number of no-load operations.

Since there are several varieties of nets/systems according to degree of elaboration, net/system comprise both downward and from bottom to top. It is more frequent from bottom to top. In this case the problem of the strategic formation of primary networks into the quotients (local), and then into the compound nets/systems appears. The so-called joining of nets/systems is conducted.

To number of total concepts should be related also question of modification of graphic representation. Here also there can be the following three varieties:

- the first - nets/systems with the orientation to the works; in

them above the arrows/pointers the designation of works is entered/written, and only number is appropriated to events;

- the second - net/system with the orientation to the events; in such nets/systems on the graphs/curves are entered/written not the designations of works, but the designations of events, but arrows/pointers indicate only communications/connection between the events;

- the third - combined orientation (it is given the designation of works and the designation of events).

Nets/systems of second and third variety are applied in plans/layouts of large/coarse scale during scheduling of generalized (enlarged).

Nets/systems of first variety are more advisable for small and average/mean nets/systems. This most frequently the technological model of plan/layout (draft/design/project). It more graphically shows the sequence/consistency of works and their interconnection.

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The nets/systems of the first variety are recommended for the

beginning of the assimilation of the network method of the planning and management.

And finally, here one should speak about division of network graphs into two varieties, connected with elements/components of uncertainty in one or the other developments.

By this sign/criterion are distinguished two types of network models: determined and stochastic (probabilistic).

By determined models are understood models, in which there are no uncertainties; in them everything is known.

Stochastic models include such, in which there are elements/components of uncertainty. For example, in the scientific research, experimental design works it is not possible to accurately establish/install expenditures of time, resources/service lives, quantity of executors/performers for the execution of one or the other particular works. In these cases the probabilistic method of the estimation/evaluation of the possible expenditures of time, resources/service lives, etc is applied.

§ 4. Order/formation of the formation of network graphs.

General rules.

There are several general rules of formation of network graphs:

- from beginning toward the end (from initial event to that completing);

- from middle toward the end and beginning;

- from end at the beginning.

We will adhere to most widely used method - from beginning toward the end from left to right each event with large reference number is depicted several more to the right preceding/previous number. Arrows/pointers can be arbitrary length and sector/direction, but compulsorily from left to right. It is necessary as far as possible to avoid the mutual intersection of arrows/pointers (Fig. 8).

For this purpose it is better to displace these or other events in the diagram or to depict arrow/pointer in the form of broken line.

Beginning compilation of net/system, it is necessary:

- to establish/install, what works must be completed earlier than will be begun this work (what works they must precede this work);

- to determine, what works they can be initiated after completion of this work;

- to explain, what works they can be fulfilled simultaneously with this work.

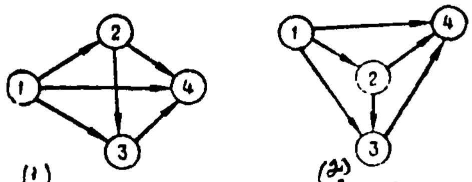

Fig. 8. Formation of net/system.

Key: (1). It is undesirable. (2). It is better.

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During formation of net/system rough version compulsorily is comprised. To the appearance of net/system in this case is given, as a rule, no attention. Rough net/system usually appears very complicatedly. Main attention is paid to the logically correct definition, the mutual sequence/consistency event.

After net/system will be comprised and checked logical communications/connections, it is possible it to regulate (Fig. 9 and 10).

However, after ordering of net/system in it can remain crossed/intersected works (arrow/pointer), this is undesirable with respect to visibility of graph/curve and convenience in work with it,

but it is completely admissible, and sometimes also it is unavoidable in view of logical communications/connections and interdependence of events in development.

In order-disorder transformation of net/system into it frequently it is necessary to add so-called "forgotten" works.

Numbering of events.

As has already been spoken, events are labeled so that larger reference number would be arranged/located several more to the right preceding/previous number along rule: number of preceding/previous event of work cannot be more than number of subsequent event of the same work.

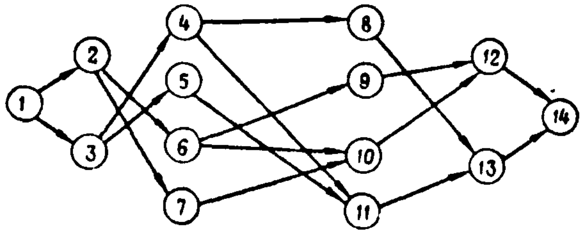

Fig. 9. Disordered image of graph/curve.

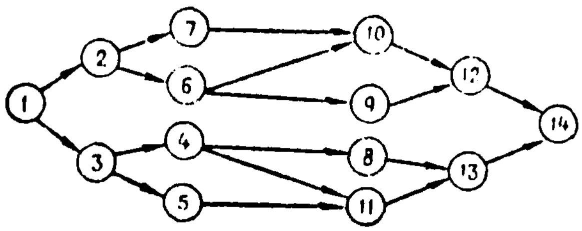

Fig. 10. Regulated image of graph/curve.

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However, during compilation of complicated nets/systems we encounter with definite difficulties with numbering of events, as a result of which are obtained errors, which then can lead to errors in calculations/crews. In order to exclude errors and to lighten work on the numbering of events in the nets/systems, the so-called method of the deletion of arrows/pointers is applied.

Essence of this method consists of following.

First appears itself on graph/curve (Fig. 11) event, which does not have entering works (such event it is always first, i.e., initial event of graph/curve) and it is appropriated to this event zero rank; we note zero number of rank above event (1).

Then all arrows/pointers, which come out from this event, are deleted (by one line), such appear themselves among subsequent events, which do not have entering arrows/pointers (except those crossed out), and is appropriated by them first rank (I).

All arrows/pointers, which come out from events of first (I) order, then are deleted (by two lines or by another color of pencil), such appear themselves among subsequent events, which do not have entering arrows/pointers, and is appropriated by them second rank (II).

Further this entire work is made in this sequence/consistency to end of graph/curve, are appropriated to current events, which do not have entering arrows/pointers, third (III), fourth (IV) ranks, etc. Events are labeled in the increasing order/formation on the ranks, beginning from the initial event.

Image of multiple operations.

During formation of network graphs complicated complex communications/connections, when two or more than works have general/common/total final event, very frequently are encountered. They are fulfilled in parallel (combined), but duration their different. The combined execution of works should be depicted so that any work could be connected only with two events. In this case it is necessary to depict the interconnection of works, introducing supplementary event and blank communications/connection (Fig. 12).

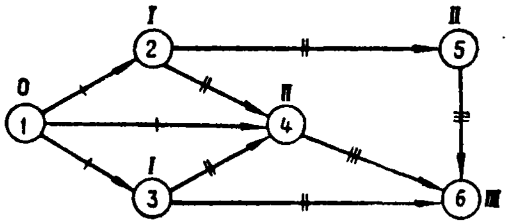

Fig. 11. Numbering of events by the deletion of arrows/pointers.

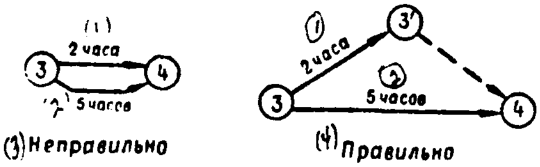

Fig. 12. Graphic representation of multiple operations.

Key: (1). 2 hours. (2). 5 hours. (3). It is incorrect. (4). It is correct.

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Image of differentiated dependent works.

During formation of network graphs can be encountered such conditions, when for execution by one of works, for example work (5, 6), in Fig. 13a, it is necessary to preliminarily fulfill several works, in Fig. 13a - work (2, 5) (3, 5) and (4, 5), and for another work (5, 7), which comes out from event (5) common for them, execution only by one of previous works (4, 5) is preliminary

condition. In this case it is not possible to depict interconnection and the dependence of works in the manner that this is shown in Fig. 13a, since with this image it is obtained, that the beginning of work (5, 7), depends on the execution of all three previous works (2, 5) (3, 5) (4, 5), but this does not correspond to development conditions.

Here, just as with image of multiple operations, should be introduced into net/system supplemental event (5') and blank communications/connection (Fig. 13b).

As has already been spoken, in certain cases by condition of beginning of one or several works (see work (5, 6) in Fig 14a) in net/system is execution of unit of any work, in Fig. 14a - work (4, 5).

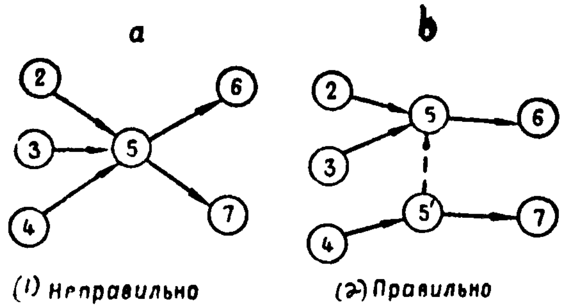

Fig. 13. Formation of net/system taking into account the dependence of works.

Key: (1). It is incorrect. (2). It is correct.

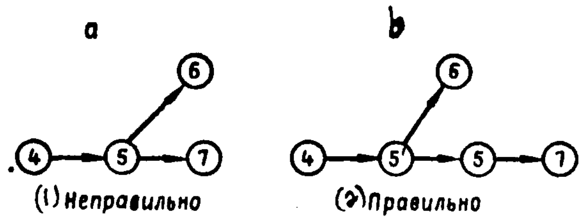

Fig. 14. Formation of net/system taking into account, when subsequent works can begin after accomplishment of unit of previous work.

Key: (1). It is incorrect. (2). It is correct.

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Therefore it would be incorrect to depict on the graph/curve (Fig. 14a) the previous work as rear sight, and then from terminal event

(5) of this work ink subsequent work (5, 6), whose beginning depends on the execution only of the unit of the previous work. In this case for the correct image of interconnection and sequence/consistency of the execution of works in the graph/curve it is necessary to divide work (4, 5) into the concretely/specifically/actually specific on the time execution component parts and to introduce supplementary event (5') (Fig. 14b).

External supports/sockets in graphs/curves.

In order to repel in draft of plan of development time and place of entrance into unit (subunit) of supplementary supplies, personnel replacement, technical documentation (for example, with realization of designing) and other information, on network graphs so-called supports/sockets depict. Outwardly supports/sockets in contrast to the works and the events it is accepted to depict particularly: as dual small circle with zero (Fig. 15).

In presence of two and more works, which come out from event, with which it is necessary to connect support/socket, latter is depicted in connection with event (Fig. 16) additionally introduced through fictitious work.

Order/formation of the display/representation of organizational

communications/connections.

With graphing it is necessary to reflect/represent not only technological communications/connections and dependences, but also for organizational communications/connection.

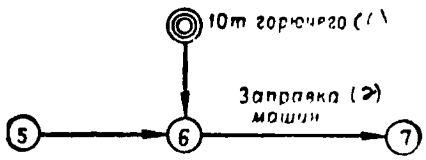

Fig. 15.

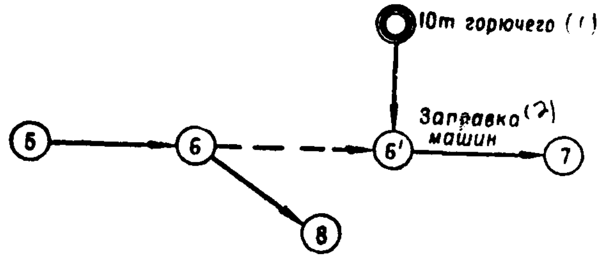

Fig. 16.

Fig. 15. Image on graph/curve of external supports/sockets.

Key: (1). 10 t of fuel. (2). Servicing of machines.

Fig. 16. Image of external supports/sockets on graph/curve in presence of two and more than works, which come out from event.

Key: (1). 10 t of fuel. (2). Set-up work.

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For example, the consecutive transportation of the brigades of repairmen and necessary equipment during the organization of restoration/reduction or servicing of armored technology under the field conditions.

Let us suppose are three works A, B, C (A - repair of running gear, B - repair of engine, C - repair and alignment of armament), which must be carried out on two tanks. For conducting the repair are three brigades of repairman-specialists for each form of the works, equipped with the necessary equipment and instrument, moreover at the beginning of repair is free only a one brigade - on the repair of running gear.

These works can be fulfilled immediately on two tanks combined, consecutively/serially transporting brigades of repairman-specialists and their armament from one (I) damaged tank to another (II). On the network graph the sequence/consistency of the execution of these works can be depicted in two ways (Fig. 17 and 18).

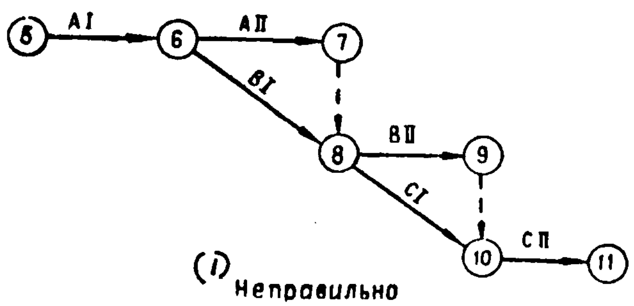

Fig. 17. Incorrect image of the sequence/consistency of the execution of technological and organizational communications/connections.
Key: (1). Incorrectly

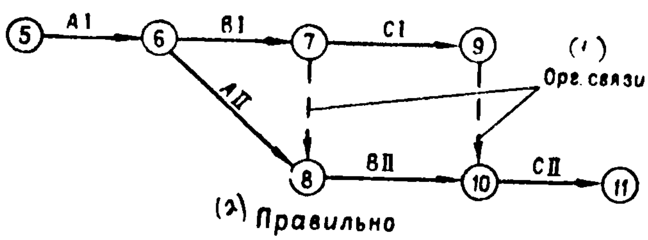

Fig. 18. Correct image of sequence/consistency of technological and organizational communications/connections.

Key: (1). Org of communications/connection. (2) Correct

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After examining graph/curve in Fig. 17, we can establish that organizational and technological communications/connections on it are shown incorrectly, since on this fragment of graph/curve of repair of tanks under field conditions by broken pointers are shown not organizational communications/connections, but technological

dependence of beginning of work on repair of engine of tank of II on termination repair of running gear of the same tank or beginning of repair of armament of termination of repair of engine and, furthermore. Completely is unjustifiably set in the dependence the beginning of work C I on the termination of work A II. Organizational and technological communications/connections in this case must be depicted in the manner that it is shown in Fig. 18.

Two-way communications.

Besides organizational communications/connections on graphs/curves can be reflected two-way communications (dependence), which, just as in other cases, are depicted as introduction of fictitious works (broken pointers).

For example, are three processes A, B, C. In this case the end of process C depends on the results of processes A and B. In this case appear the bilateral dependences, which can be depicted in the manner that this is shown in Fig. 19.

However, introducing into net/system fictitious works, one should consider that their quantity and sector/direction of broken pointers (communications/connections) can be reflected in critical path (Fig. 20).

As we see from Fig. 20a, fictitious work (2, 3) does not have effect on critical path in other case (Fig. 20b) with change of sector/direction of dependence in the same development fictitious work it led to increase in duration of critical path.

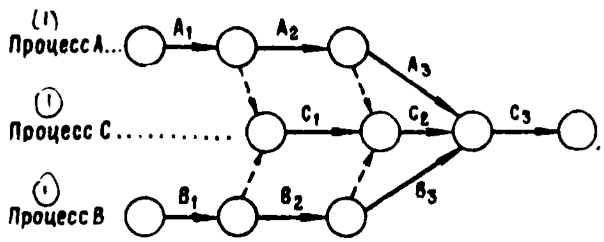

Fig. 19. Image of the dependent processes.

Key: (1). Process.

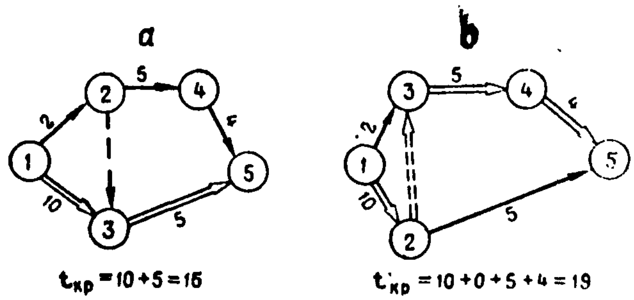

Fig. 20. Effect of sector/direction of fictitious works to length of critical path.

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Therefore, introducing into the net/system fictitious (blank) works, each time it is necessary to strictly analyze the need for one or the other communications/connection (dependence) in the development.

Simplification in the nets/systems.

During formation of network graphs it is sometimes expedient to enlarge work by replacing totality of works by one "aggregate" work, if some group of works has one initial and one final event (Fig. 21). This figure shows the simplest example of coarsening/consolidation of works.

However, in practice more frequently are encountered cases, when group of works, which has one initial and one final event, cannot be substituted by one "aggregate" work due to communications/connections of individual works of group through intermediate events with other units of network graph. In this case the nets/systems of the undertaken group of works (Fig. 22) are usually limited to simplification.

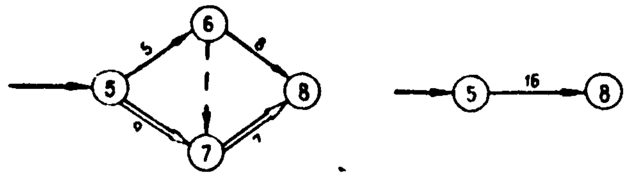

Fig. 21. Replacement of the totality of works by one "aggregate" work.

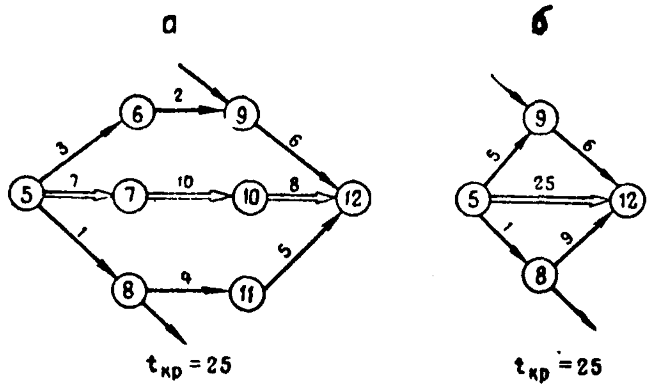

Fig. 22. Replacement of totality of works in nets/systems with events, which have intermediate couplings.

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In Fig. 22a we see that initial net/system it is not possible to replace with one "aggregate" work, as this we made in first case, since she was connected through events (8 and 9) with other units of network graph of entire development. We simplified net/system, but are left in it events (8 and 9), without disrupting

communications/connections of the process in question with other units of network graph (Fig. 22b).

This simplification in nets/systems considerably improves visibility of common network graph, simplifies its calculation/crew and optimization.

Inspection/check of the correctness of the compilation of net/system.

Network graph comprised using rules described above usually is inspected/checked.

During inspection/check they explain, no whether on schedule of operations, which have identical codes (especially for multiple operations). If such works are discovered, then should be introduced supplementary events and fictitious works.

Then is inspected/checked graph/curve to presence of blind events, i.e., events, from which begins not one work, except graph/curve completing events. If such events are discovered, then the works, entering such events, and events themselves must be excluded from the graph/curve. It is also necessary to exclude such events, besides the initial event, which precedes not one work.

And finally, is inspected/checked order/formation of image differentiated dependent works, organizational communications/connections, and also no whether in graph/curve of locked ducts/contours (Fig. 5).

In complicated developments after inspection/check of primary and local network graphs joining (strategic formation) them into summary network chart of development as a whole is conducted.

Joining nets/systems.

Above discussion centered on the fact that according to degree of elaboration and purpose/designation network graphs in complicated developments are divided into primary, particular (local) and compound nets/systems. This division makes it possible to determine the level of the elaboration of network graphs and it creates more favorable conditions for the monitoring/checking of the course of the development and control of it, allows during scheduling of the initial of development as a whole to draw for this work of specialists or commanders (executors/performers) of the subordinates of units (subunit) or departments, which well know sequence/consistency, volume and qualitative evaluations of works in its component/link.

In connection with this division of network graphs according to degree of their elaboration during scheduling of compound of development as a whole need for strategic formation (joining) of particular (local) graphs/curves into general/common/total (compound) net/system appears.

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The process of joining nets/systems is accompanied/tracked by development/detection and elimination of mismatches, different discrepancies and by simplification in the local graphs/curves. For convenience in joining nets/systems and for the purpose of the exclusion of the repetition of the codes of works in the summary chart to each executor/performer (subunit, department) for the numbering of events they give the specific quantity of numbers and are determined (they coordinate) the intake or output boundary events of the developed/processed by them nets/systems. For the clarity to each subunit (department) can be established/installed its conventional sign of events (Fig. 23).

Quantity of numbers is allotted to departments (subunits) with reserve. For example, to the first subunit from No 121 to No 140, the second - from No 140 to No 160, etc.

Joining nets/systems can be conducted in detail, when particular nets/systems are joined in essence in that form, in which they are represented into higher headquarters or coarsely, when compound net/system is composed mainly from "aggregate" works, which encompass whole complex of measures (works), themes realized or by another department (subunit).

Joining nets/systems is more frequently conducted from bottom to top from lowest ones to highest echelons of command on boundary events. Moreover such events, which are connected with works with other responsible executors/performers of subunits (departments) and are, thus, are called boundary events general/common/total for two and more than nets/systems. Boundary events can be intake (in Fig. 23 10, 20 and 40 respectively for 1, 2 and the 3rd of departments) and output (in Fig. 23 10, 20 and 40 respectively for the command, the 1st and 2nd departments).

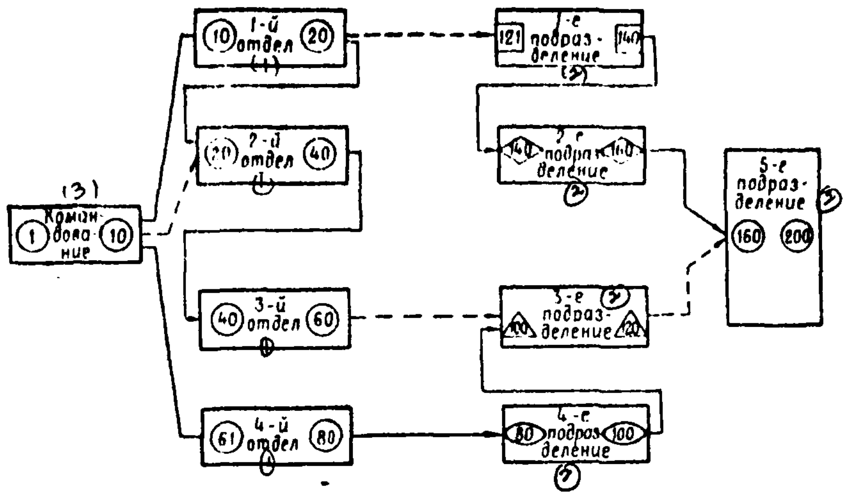

Fig. 23. General diagram of joining net/system.

Key: (1). department. (2). subunit. (3). Command.

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They show intake events, what complex of results of works must be obtained to this executor/performer from other responsible executors/performers. Those results of the works, which it must transmit to another responsible executor/performer, in turn will be output event for this executor/performer. For example, event (5) the "repair of the engine of tank is completed" (Fig. 24) it will be the output boundary event of the particular network graph of one repair subunit and intake boundary event for the net/system of another subunit, which realizes assembling of assemblies on the tank.

Fig. 24 shows procedure of joining nets/systems. As we see, nets/systems are connected on the transfer event, then are traced all remaining elements/components of particular graphs/curves (if is not conducted their simplification or coarsening/consolidation) and additionally conditional are introduced initial and completing the events (they are shown by broken small circles).

Input/introduction of conditional ones of initial and terminal events has important value for subsequent calculations/crews according to summary network chart. In the cross-linked net/system then they enter/write numbering of events through for entire graph/curve, leaving in the small circle of each event and the old number (Fig. 25), so that, in the compound net/system it would be it is easy to determine, what subunit (department) bears responsibility for the execution of one or the other work.

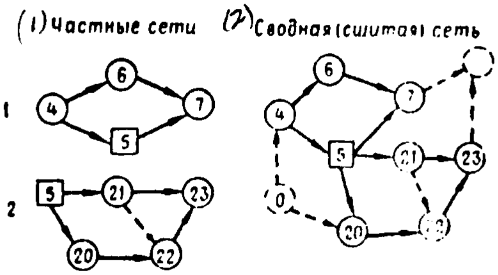

Fig. 24. Procedure of joining nets/systems. (2). Particular nets/systems. (3). Compound (cross-linked) net/system.

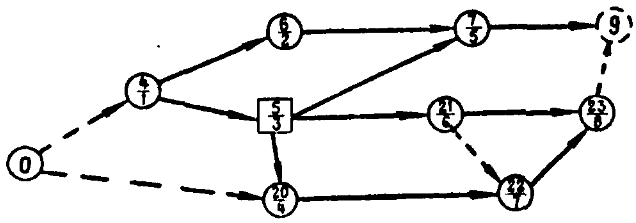

Fig. 25. Possible numbering of events in cross-linked net/system.

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In complicated developments during joining of primary graphs/curves and particular nets/systems specific number of works and events, according to which responsibility is laid in individual subunits, can be omitted and is substituted "aggregate" works, since details of individual particular problems do not have vital importance for higher level of control. For example, during the creation of new equipment models or at the repair plant the construction (assembly) of the defined assemblies (units) of

vehicle/computer, which consists of number/series of individual works, is included/switched on in the compound net/system as one independent work (Fig. 26).

Such are fundamental rules and technical receptions/methods of scheduling network, which should be been guided, taking up network planning or analysis of any processes (developments) in military affairs.

Sequence/consistency of work during scheduling of network.

Formation of network graphs must be based, first of all, at comprehensive analysis of basic and intermediate objectives of development.

First stage of work on compilation of network model of one or the other process in military affairs - this is formulation of mission, which determines final goal of development. However, besides basic (final) purpose in the development should be emitted intermediate objectives, which must be interlocked both on the sequence/consistency and according to the results of their reaching/achievement.

Intermediate objectives determine level of execution of program

and they are particular problems, which must be solved for achievement of basic goal. For example, the final goal for the development, which simulates the march of unit into the area of exercises, will be the concentration of unit to the specific time, let us say in area A, B, C in readiness for the execution of combat task/mission, and they will respectively be intermediate objectives of this development:

- organization of the march of unit;

- completion of march and concentration subunit in area A, B, C;

- bringing subunits into the order/formation after march in the new concentration area.

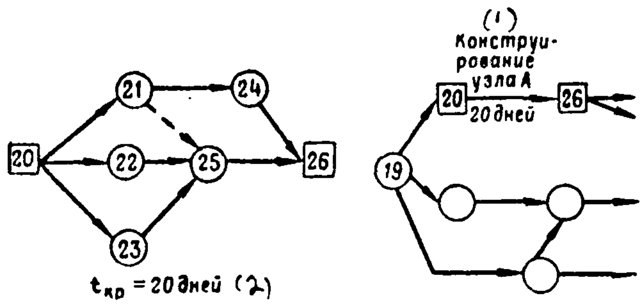

Fig. 26. Replacement of unit by one work during scheduling of compound.

Key: (1). Construction of unit A of 20 days. (2). days.

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Second stage of work, which precedes scheduling network, consists in compilation of block diagram of development, or so-called "tree/wood of development", which must clearly show volume and stages of works.

For compilation of block diagram ("tree/wood of development") entire/all program (system) is divided into subsystems, subsystems in turn are divided into complexes, complexes - to individual elements/components.

Block diagram should be developed/processed first of all in

complicated plans/layouts, when there are several intermediate objectives, and they in turn can have their subgoals. The special feature/peculiarity of this complicated structure is presence at each level of number/series of the independent final or intermediate units (subunits), which carry out their missions independently of each other. However, a number of the levels in the structure depends mainly on the complexity of program and can be different for the individual branches of structure. one branch is developed it sufficiently in detail and has many levels, another - achieves its end at the second or third level and further is not divided.

Preliminary development of block diagram increases visibility of diagram/plan/circuit of development,.it establishes/installs clearer interconnection between its separate units and simplifies leadership/manual in limits of each level.

Senior commander (higher headquarters), who determines degree of development of development (lowest level, it assigns responsible executors/performers of works in component parts of development (besides authorized ones) and gives initial data for network planning to responsible executors/performers must be critical for development of structural tree/wood.

Exemplary/approximate version of block diagram of development ("

tree/wood of development"), target of which is creation of new vehicle/computer (let us name/call it conditionally "Objective T-100"), is shown in Fig. 27.

When compilation of block diagram will be acknowledged unsuitable, development of overall volume of works can be performed by another route/path - by scheduling enlarged network (Fig. 28).

Third stage of work on scheduling of network - these are compilation of enumeration of works in each component/link of development and formation of their temporary/time estimations/evaluations.

Enumeration of works can be brought to table, whose form is given in Table 1.

Table 1.

№ по пор.	Наименование работ	Код работ	Продолжительность работ, мин
1	Уяснение задачи	(1, 2)	10
2	Предварительные распоряжения подразделениям	(2, 3)	30
3	Оценка обстановки и т. д.	(2, 4)	60

Key: (1). No on pores. (2). Designation of works. (3). Code of works. (4). Duration of operations, min. (5). Understanding problem. (6). Warning orders to subunits. (7). Estimation/evaluation of situation, etc.

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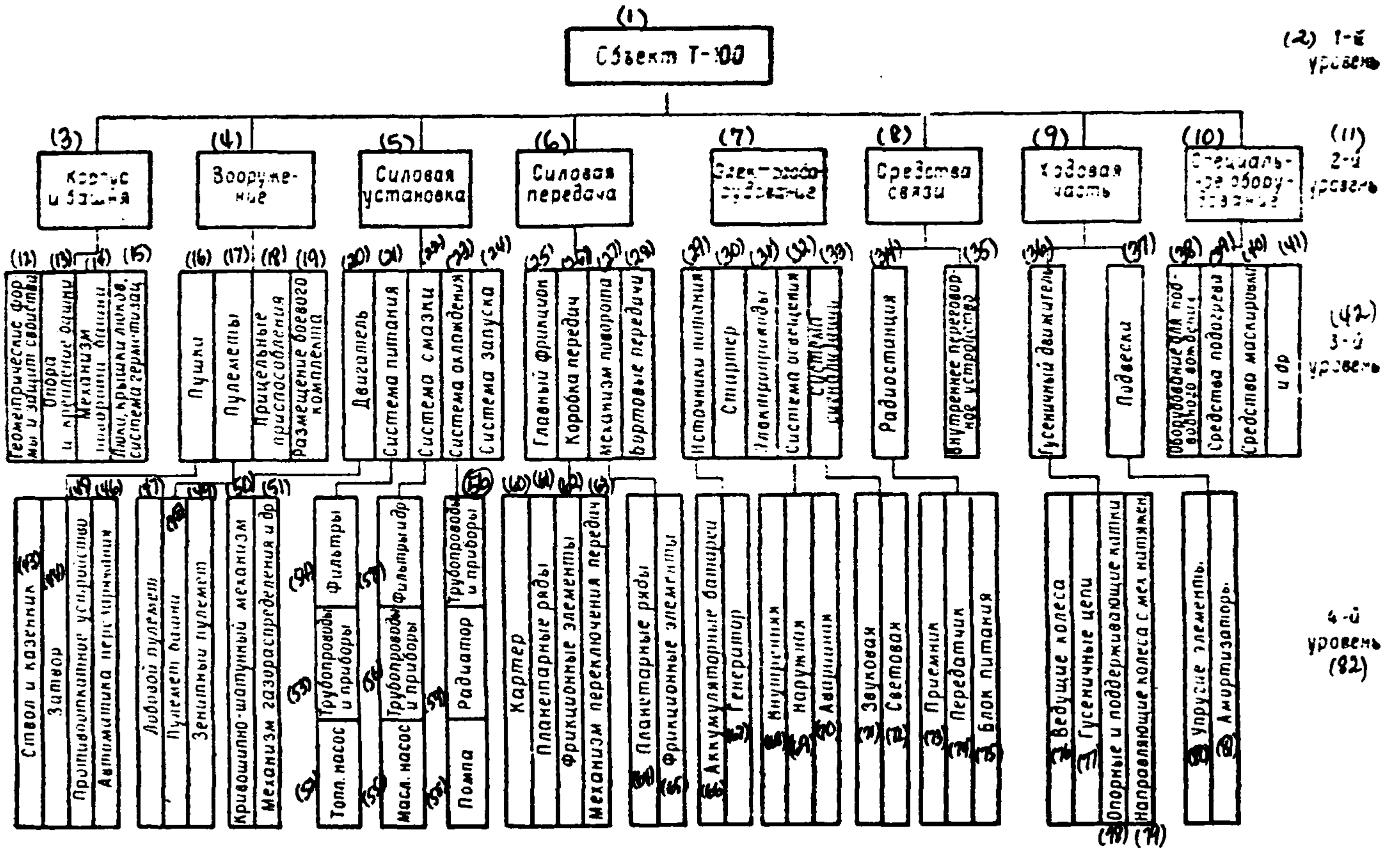

Fig. 27. Structural "tree/wood of development".

Key: (1). Objective T-100. (2). 1st level. (3). Housing and turret. (4). Armament. (5). Power plant. (6). Power transmission. (7). Electric equipment. (8). Communications. (9). Running gear. (10). Special armament. (11). 2nd level. (12). Geometric forms and defenses of property. (13). Support and attachment of turret. (14). Turret traversing mechanism. (15). Hatches, hatch cover, system of sealing.

(16). Gun. (17). Machine guns. (18). Sight mechanisms. (19). Arrangement/position of combat set. (20). Engine. (21). Power-supply system. (22). Lubrication system. (23). Cooling system. (24). Starting system. (25). Engine clutch. (26). Gearbox. (27). Mechanism of rotation. (28). Onboard transmissions. (29). Power supplies. (30). Starter. (31). Electric drives. (32). Lighting system. (33). Signaling system. (34). Radio set. (35). Internal negotiatory device. (36). Tracked propeller/motor. (37). Suspension. (38). Armament for underwater driving. (39). Means/facilities of preheating. (40). Means/facilities of deception. (41). etc. (42). 3rd level. (43). Barrel and breech ring. (44). Breechblock. (45). Antigravity device. (46). Automation of reloading. (47). Frontal machine gun. (48). Machine gun of turret. (49). Antiaircraft machine gun. (50). Crank gear. (51). Valve actuating mechanism, etc. (52). Fuels pump. (53). Pipelines and instruments. (54). Filters. (55). Oil pump. (56). Pipelines and instruments. (57). Filters, etc. (58). Pump. (59). Radiator. (60). Crankcase. (61). Planetary number/series. (62). Frictional elements/components. (63). Gearshift. (64). Planetary number/series. (65). Frictional elements/components. (66). Storage batteries. (67). Generator. (68). Internal. (69). external. (70). Emergency. (71). Sonic. (72). Light. (73). Receiver. (74). Transmitter. (75). Power pack. (76). Drive wheels. (77). Tracked targets. (78). Supporting/reference and holding cylinders. (79). Guide wheels with mech. tension. (80). Elastic elements. (81). Shock

absorbers. (82). 4th level.

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Complex "Code of Works" in table can be filled, also, after scheduling of initial. As far as the formation of the temporary/time estimations/evaluations of works is concerned, for the frequently repeating works, on which there are specific norms of time, the operating time is entered/written in accordance with these norms taking into account specific situation conditions.

In the same cases, when objectively substantiated norms of time of operating time are absent (in scientific research, experimental design and other works), they resort to probabilistic method of definition/determination of their duration. The procedure of the formation of temporary/time estimations/evaluations according to this method is presented in Chapter II.

Then on the basis of enumeration of works in each component/link initial network graph is comprised, is conducted its miscounting and analysis, on basis of which is determined, to what degree initial graph/curve it corresponds to aspect of problem presented. If the initial network graph of the execution of the complex of works does not provide the timely accomplishment of objective, then the

optimization (improvement) of graph/curve in the interests of timely achieving of the goal of development in this component/link is realized.

Optimized graphs/curves of subunits (departments) are represented into higher headquarters, where summary network chart is developed/processed.

However, sometimes in research developments to commanders of subunits (responsible executors/performers) at stage of compilation of initial plan/layout upon formulation of problem to analysis of model of complex of one or the other measures for the purpose of larger objectivity of estimations/evaluations of periods of execution of development will not be indicated desirable or necessary calendar periods of execution of assigned to them works.

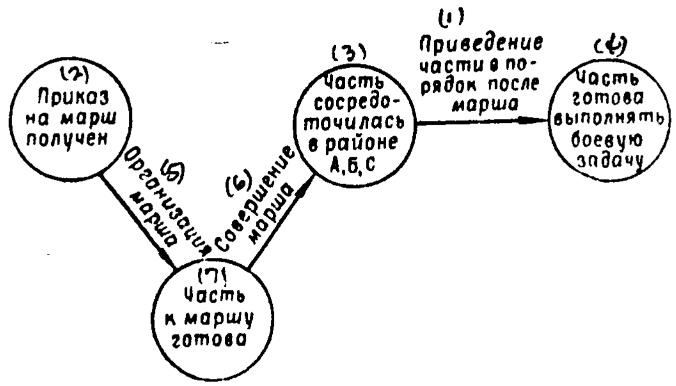

Fig. 28. Enlarged network graph.

Key: (1). Bringing unit into the order/formation after march. (2). March order is obtained. (3). Unit was concentrated in area A, B, C. (4). Unit is ready to make combat task/mission). (5). Organization of march. (6). Completion of march. (7). Unit to march is ready.

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In this case responsible executors/performers will determine only the duration of individual operations, sequence/consistency of their execution and logical communications/connections of works without depending on the calendar periods of their execution, which can be soundly determined only as a result of the calculation/crew of net/system.

Summary network chart of development as a whole after inspection/check and elimination of all disagreements and discrepancies cheats in counting, it is analyzed and if necessary again is optimized.

This graph/curve depending on quantity of works included by it and events can be depicted completely or be enlarged net/system with fragments of most important details.

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Chapter II.

CALCULATION OF PARAMETERS OF NETWORK GRAPHS, WHICH REFLECT THE COMBAT ACTIVITY OF FORCES.

1. Formation of temporary/time estimations/evaluations of works.

During planning of combat operations of troops/forces network graphs will be, as a rule, comprised on time. Therefore the calculation/crew of these graphs/curves and their optimization, i.e., improvement, are conducted precisely from this parameter. However, together with this the network graphs, which reflect the activity of the troops/forces, can be comprised not from the time parameters, but for example, according to the expenditure/consumption or on the delivery of the material resources on the money expenditures. In these cases and the calculation/crew of net/system must be conducted from the appropriate parameter, from which is comprised the net/system.

In this labor/work nets/systems, comprised from time parameter, are examined.

Duration of each operation on time is entered/written usually in process of compilation of net/system. During the compilation of net/system, as soon as two events are determined and the work, which connects these events, above the work is written its designation, and under it - the time of its duration in the seconds, the minutes, the hours, the days or the weeks (depending on the character of process and convenience in the work with the network graph).

It is necessary to keep in mind the circumstance/case/fact that correctness of entering of time characteristics has fundamental importance. Quality graph/curve and operational efficiency of leadership/manual of process according to this graph/curve will depend on the correctness of the assigned temporary/time estimations/evaluations. If, for example, the periods of the execution of works will be understated, i.e., they are undertaken smaller than it is necessary for their production, then this will cause haste in preparation/training for the performance of one or the other work and entire operation/process as a whole. Similar haste, as the experience/experiment/lesson of the last war showed, can lead to the disruption/separation of combat operations and, consequently, also to the unjustified and useless victims. It is understandable

that under similar conditions the target of battle will not be achieved.

Overestimate of periods of execution of individual works, on the contrary, can lead to delay of period of beginning of combat operations, i.e., to useless and unjustified time loss, which can use enemy and strengthen his defense or be prepared and apply counteroffensive.

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But where to take estimations/evaluations of operating time, which most correspond to reality?

For this there are two capabilities.

For works or for operations/processes, on which is accumulated sufficiently large experience both into peaceful and in wartime, estimations/evaluations can be taken from accumulated experience/experiment/lesson, i.e., such estimations/evaluations can be taken unambiguously from norms, derived in course of combat training or in course of combat operations.

Legitimacy of single-valued selection of such temporary/time

indices/measures is based on probability theory.

In military affairs as a whole we always deal concerning random variables. From the probability theory it is known that with the large number of tests arithmetic mean quantity/magnitude the value of random variable in effect/virtually remains the constant (it ceases to be changed). In other words, with a large number of independent experiences/experiments/lessons arithmetic mean the obtained values of random variable M*[X] converges/meets on the probability with its mathematical expectation M[X]. Such communications/connection between arithmetic mean and mathematical expectation of random variable composes content of one of the forms of law of large numbers. This is exceptionally/exclusively important for the practical activity in that sense, that when a large number of experiences/experiments/lessons is present, the statistical (sample) value of datum is taken, considering it that differing little from the real. Therefore the use of statistical, i.e., experimental data, is the scientifically substantiated approach to the decision/solution of any kind of the problems, connected with the random processes.

Important conclusion/derivation hence ensues/escapes/flows out: it is necessary to accumulate experimental data from all works, connected with combat activity of troops/forces, and to reduce them to reference standard tables and catalogs. This remains valid and

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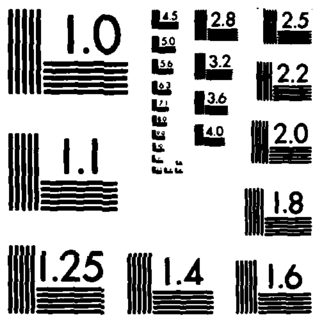

MICROCOPY RESOLUTION TEST CHART
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according to the relation/ratio of the expenditures of resources/service lives (human, material, money, energy). Having such standard catalogs, it will be easy to enter/write temporary/time and other parameters in the network graphs.

Thus, one of capabilities of definition/determination of temporary/time and other characteristics, necessary for estimation/evaluation of duration of works or expenditure/consumption of resources/service lives and their entry in network graphs, is use of statistical data, obtained experimentally.

There is another capability of obtaining characteristics indicated above. It is based on the probabilistic methods of the definition/determination of random variables. The fact is that in random either stochastic processs, on which there is no adequate experience, or in the completely new processes, according to which there is generally no experience/experiment/lesson, has the capability to also determine the quantitative evaluation of random phenomena. This quantitative evaluation can be determined on the probability of the appearance of this event. In effect/virtually for this it is expedient to enter thus.

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For the works, according to which there are no temporary/time estimations/evaluations, by experienced commanders or by engineers (executors/performers of graph/curve) are given three estimations/evaluations of the time: optimistic, pessimistic and most probable.

Optimistic estimation/evaluation - is smallest of possible ones operating time, i.e., time, during which work can be carried out with most favorable confluence of circumstances/cases/facts. Let us designate this estimation/evaluation through t_{min}. The probability of the execution of work for this time, as it is known from the experience/experiment/lesson, in the majority of the cases is approximately 0.01.

Pessimistic estimation/evaluation - is greatest of possible ones, according to experience of executor/performer, operating time, i.e. time of performance of work with extremely unsuccessful confluence of circumstances/cases/facts. Let us designate this estimation/evaluation through t_{max}. The probability of the execution of work for this time also is approximately 0.01.

Most probable estimation/evaluation - this possible time of execution of this work when will arise no unexpected difficulties. Let us designate this estimation/evaluation through $t_{n.n.}$ The

probability of the execution of work for this time will be maximum.

If we require of executors/performers of works only one estimation/evaluation instead of three, then this can lead to the fact that estimation/evaluation can prove to be high or understated, i.e., unreal. But the unreal life or the unreal material expenditures, indicated in the graph/curve, can lead to the same countings/reckonings/errors, which frequently are encountered during planning of processes with the aid of the linear graphs/curves, i.e., with the aid of the existing now traditional methods.

Probability of execution of work for time smaller than optimistic estimation/evaluation, will be very low. Analogous with low there will be the probability of the execution of work for the time, which exceeds pessimistic estimation/evaluation. Greatest will be the probability of the execution of work for the time of realistic estimation/evaluation, i.e., for the time of the most probable estimation/evaluation of time. Based on this at first glance it can seem that it is necessary to use the most probable estimation/evaluation of time. However, if everything is good to weigh, then one ought not to enter.

Let us examine this based on specific example.

It is known that number of goggles, driven out on firing range with firing, is random variable, which is characterized by certain probability distribution for each rifleman. Executing a fire mission, each soldier can knock out certain minimum, maximum and most probable quantity of goggles. The assumed estimation/evaluation of a quantity of goggles for each soldier with the next shot is very similar to the assumed estimation/evaluation of the time, necessary for the execution of each work in our case. Let us allow now that on the basis of the study of the targets of one soldier they established that a quantity of goggles driven out by it is characterized by statistical number/series, given in Table 2.

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From this number/series we see that entry/incidence into nine (p=0.6) is most probable. If the most probable estimation/evaluation is taken for the criterion, then it is possible to assume that this soldier of 100 shots will knock out 900 eyes. But this will be erroneously. From the probability theory we know that in order to correctly determine the assumed number of goggles, which will be knocked out by soldier, it is necessary to find certain averaged quantity/magnitude. For this it is necessary to multiply values of random variable for the probabilities corresponding to them and to accumulate the obtained results. For our example mean arithmetic

value will be equal to 8.83. As is evident, the here expected value differs from most probable, which is equal to 9. Thus, a number of goggles obtained by soldier with 100 shots will be close to 883.

Consequently, if we during definition/determination of temporary/time estimations/evaluations take only one realistic or most probable estimation/evaluation, then let us complete the same error, as in the case with soldier. This error will not be, if three temporary/time estimations/evaluations will be used for calculating the expected time of the execution of each work.

In theoretical sense solution of this problem is connected with some mathematical difficulties, since for this it would be necessary to know probability distribution function, by which operating time is characterized.

When commander assigns three estimations/evaluations of time of duration of execution of certain operation/process, i.e., he gives optimistic, most probable and pessimistic estimation/evaluation, then thereby it determines certain probability distribution, analogous to given in Fig. 29 distributions.

Table 2.

(1) Вероятность (p)	0,2	0,6	0,1	0,05	0,03	0,02	0,00
(2) Случайная величина (выбитые при стрельбе очки)	10	9	8	7	6	5	1

Key: (1). Probability (p). (2). Random variable (knocked out with firing goggles).

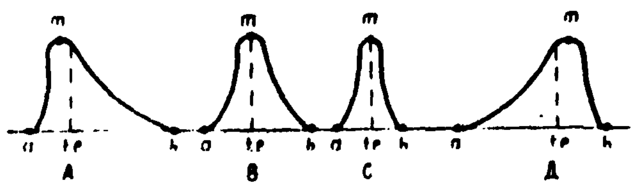

Fig. 29. Some probability distributions: a) optimistic estimation/evaluation of operating time; m - most probable estimation/evaluation of operating time; b - pessimistic estimation/evaluation of operating time; t_e - average operating time, if this work was repeated repeatedly.

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Quantity/magnitude t_e for each of distributions given in Fig. 29 is mathematical expectation or statistical average value of three estimations/evaluations of operating time. In other words, quantity/magnitude t_e is average duration of this operation in the case of its multiple repetition.

Relative attitudes of quantities/magnitudes a, m and b (Fig. 29) depend on numerical values of these quantities/magnitudes, given by commander. Their relative attitudes in turn determine value or position/situation of quantity/magnitude t_e.

Value of quantity/magnitude t_e according to three estimations/evaluations is determined from formula

$$t_e = \frac{a + 4m + b}{6}. \qquad (1)$$

Here we will not give derivations of this formula, but let us accept it as result of analysis. Special analysis and experience/experiment/lesson of the use/application of network methods show that the given formula is a reasonable compromise between the possible accuracy of result and the justified unwieldiness of calculating process.

However in order to be confident in value of expected time of execution of works, which it remains nevertheless random variable, necessary to know, we commit what error in our estimation/evaluation, i.e., to what quantity/magnitude actual time of execution of works can deviate from expected values. For the estimation/evaluation the measures of possible ones deflection from the expected value use

usually the sums of the products of the squares of differences in the random variables and their mathematical expectations at the value of the probabilities of these random variables. Obtained thus quantity/magnitude, which characterizes the possible scatter of random variable relative to its expected value, is called variance (dispersion).

Random variables are discontinuous and continuous; therefore variances for these quantities/magnitudes are determined respectively according to formulas:

for discontinuous quantities/magnitudes

$$D[X] = \sum_{i=1}^{n} (x_i - m_x)^2 p_i; \quad (2)$$

for analog quantities

$$D[X] = \int_{-\infty}^{\infty} (x_i - m_x)^2 fx\, dx, \quad (3)$$

where D[X] - variance;

x_i - value of random variable;

m_x - mathematical expectation of random variable;

p_i - probability of obtaining value of random variable.

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For network planning important is the fact that general/common/total variance of distribution of sum of many mutually independent random variables is equal to sum of values of variances of distribution for each random variable individually.

To reader, unknown with probability theory, for practical definition/determination of variance we recommend to use formula

$$\sigma^2 = \left(\frac{b-a}{6}\right)^2, \qquad (4)$$

where σ^2 - variance;

b - pessimistic estimation/evaluation;

a - optimistic estimation/evaluation.

This formula and curves in Fig. 29 show that, the more widely are located optimistic and pessimistic estimations/evaluations, i.e., is the greater spread/scope of distribution, the greater uncertainty, connected with operation/process in question, and, on the contrary, the less variance, the more precise estimation/evaluation of duration of operation/process, and therefore optimistic and pessimistic

estimations/evaluations lie/rest nearer to each other.

For example, assume that two commanders determined duration of some one and the same operation, whose estimation/evaluation was given in Table 3.

In order to determine, what commander more correctly determined operating time, it is necessary to calculate variance for each of them:

$$\sigma^2 = \left(\frac{6-2}{6}\right)^2 = \left(\frac{4}{6}\right)^2 = (0{,}67)^2 = 0{,}45;$$

$$\sigma^2 = \left(\frac{11-8}{6}\right)^2 = \left(\frac{3}{6}\right)^2 = (0{,}5)^2 = 0{,}25.$$

Calculation/crew shows that in second commander variance is less, therefore, his estimations/evaluations are more true/reliable/certain. Hence it follows that must be taken them for the calculations/crews.

Table 3.

(1) Наименование	(2) Оптимистическая (a)	(3) Наиболее вероятная (t_{n})	(4) Пессимистическая (b)
(5) Первый командир	2	4	6
(6) Второй командир	8	10	11

Key: (1). Designation. (2). Optimistic (a). (3). Most probable. (4). Pessimistic (b). (5). First commander. (6). Second commander.

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Thus, in order to determine, in whom it is less than confidence in its estimations/evaluations, it is necessary to calculate variance of each framing of estimations/evaluations and to compare obtained variances.

However, calculation/crew of expected time of execution of work can be conducted, also, on two estimations/evaluations of time. Experience/experiment/lesson shows that the definition/determination of the most probable estimation/evaluation of time always causes difficulty in the executors/performers of works, whereas the definition/determination of optimistic and pessimistic estimations/evaluations does not cause similar difficulty.

Taking into account this, Soviet scientists D. I. Golenko and V. S. Michealson proposed to determine expected time according to two estimations/evaluations. The equations proposed by them appear as follows:

- for calculating the expected time of the duration of the operation

$$t_e = \frac{3a + 2b}{5}; \qquad (5)$$

- for calculating the variance

$$\sigma^2 = 0{,}04\,(b - a)^2, \qquad (6)$$

where a - optimistic estimation/evaluation;

b - pessimistic estimation/evaluation.

At present many they prefer for definition/determination of expected time of operating time to use formula (5), since special research proved that difference as a result in comparison with time, obtained according to formula (1), can comprise only to 1%. This difference of any great practical value does not have.

Thus, summing up sum said in this section, it is possible to conclude that temporary/time estimations/evaluations for entry of duration of execution of works, connected with military affairs, must be taken from standard catalogs, regulations, manuals and summary

tables.

In connection with this before military specialists problem in making/working out/producing of norms and compilation of standard handbooks for all works, which are powerful to occur in course of combat operations, stands. For this it will require the conducting of large number of experiments and experiments, as a result of which to establish the necessary required time for the accomplishment of each work. For the works, the time of execution of which does not succeed in establishing/installing experimentally, expedient to utilize a probabilistic method of the definition/determination of their duration. All obtained thus temporary/time estimations/evaluations must be brought together to the reference standard catalogs and sent out to their troops/forces. From these standard handbooks the commanders and military engineers must take the temporary/time estimations/evaluations of works.

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In the same cases, when in reference catalogs does not prove to be temporary/time estimations/evaluations and will not be accumulated experience/experiment/lesson according to any types of work, for definition/determination of operating time it is necessary to use formula (1) or (5).

2. Calculation/crew of the parameters of network graph.

When net/system is comprised, cross-linked and checked, they begin calculation/crew of its parameters.

Calculation/crew of parameters of network graph consists in definition:

- early and late periods of accomplishment of events;

- time of early and late beginning and termination of works;

- critical path;

- all forms of reserves for works (total/full/complete and local reserves of first and second forms).

In stochastic nets/systems, besides this, into calculation/crew they enter:

- definition/determination of variances of works;

- definition/determination of probability of accomplishment of junction/unit events or entire process in estimated time.

Before beginning calculation/crew of parameters of net/system, we will be introduced to design diagram and basic conventional designations. For this let us take number/series of the works, produced by commander during the organization of offensive (Fig. 30).

Calculation diagram shown in Fig. 30 is chain/network of events and works of specific sequence/consistency, where:

h - event, from which works, directly entering preceding event, emerge;

i - initial or preceding event of work (i, j);

j - final or subsequent event of work (i, j);

k - event, into which works, which come out from subsequent event, enter;

(h, i) - previous work;

(i, j) - this work;

(j, k) - subsequent work.

Design diagram facilitates understanding physical sense of network graph.

There are several methods of calculation of nets/systems: analytical, tabular and graphic.

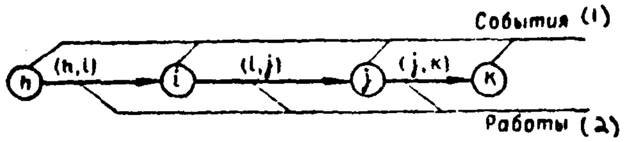

Рис. 30. Расчетная схема

Fig. 30. Design diagram.

Key: (1). Events. (2). Work.

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§5. Analytical calculation method.

With analytical method formulas are utilized; therefore we will be introduced to designations, used during calculations.

$t_{(i,j)}$ - duration of operation (i, j);

$t_{(h,i)}$ - duration of previous operation (h, i);

$t_{(j,k)}$ - duration of subsequent operation (j, k);

$t_{p(i)}$ - time of early accomplishment of event (i);

$t_{n(i)}$ - time of late accomplishment of event (i);

$t_{р.н(i,j)}$ - time of early beginning of work (i, j);

$t_{п.н(i,j)}$ - time of late beginning of work (i, j);

$t_{р.о(i,j)}$ - time of early termination of work (i, j);

$t_{п.о(i,j)}$ - time of late termination of work (i, j);

$L_{1(i)}$ - maximum, preceding event (i) route/path;

$L_{2(i)}$ - maximum, subsequent after event (i) path;

$t_{(L)}$ - duration of any route/path;

$t_{кр}$ - duration of critical path;

$P_{(L)}$ - total/full/complete reserve is temporary/time route/path (L);

$P_{(i)}$ - reserve of time of event (i);

$P_{п(i,j)}$ - total/full/complete reserve of operating time (i, j);

$P_{c(i,j)}$ - free reserve of operating time (i, j);

$P'_{n(i,j)}$ - local reserve of time of first form of work (i, j);

$P''_{n(i,j)}$ - local reserve of time of second form of work (i, j);

$K_{n(i,j)}$ - coefficient of intensity/strength of work (i, j);

$K_{c(i,j)}$ - coefficient of freedom of work (i, j).

After being introduced to principal notations and terms, used during calculation/crew of network graphs, let us pass directly to calculation/crew of parameters of network graphs.

Definition/determination of the early and late periods of the accomplishment of events.

For calculation/crew of parameters of network graphs it is necessary to know earliest of possible periods of accomplishment of events $t_{r(i)}$ and latest of permissible periods of accomplishment of events $t_{n(i)}$.

For example let us examine network graph of training tank battalion for offensive (Fig. 31) under conditions, when battalion commander is located on terrain in sector/direction of forthcoming activities, was obtained problem, also, to it profit company commanders for obtaining combat task/mission. Battalion is situated in the concentration area in 3 km from the expectant ones of position, assigned to battalion. Readiness for the assumption of the offensive for 2 h 10 min after obtaining of problem. Let us determine the early and late periods of the accomplishment of events.

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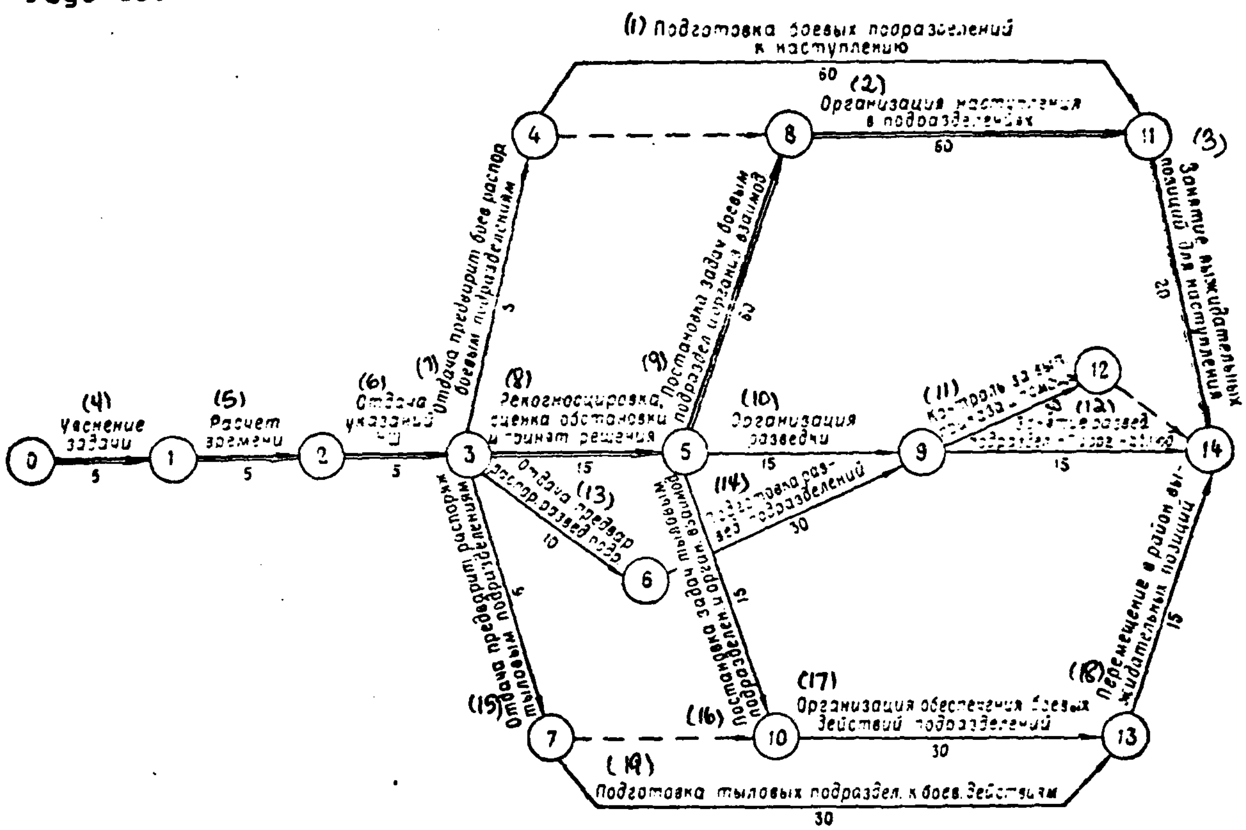

Fig. 31. Network graph of training tank battalion for offensive from position/situation of direct contact with the enemy (example).

Key: (1). Preparation of combat subsections for the offensive. (2). Organization of offensive in subunits. (3). Taking expectant positions for offensive. (4). Understanding problem. (5). Timing. (6). Issue of instructions NW. (7). Issue of preliminary combat instructions to combat subunits. (8). Reconnaissance, estimate of

situation of accepted decision/solution. (9). Formulation of problems of combat subsection and organization of cooperation. (10). Organization of reconnaissance/intelligence. (11). Monitoring/checking for iss. of order and help. (12). Exercise of recon. subsection NP and org of observations. (13). Issue of preliminary instructions of recon. subunits. (14). Preparation of recon. subunits. (15). Issue of preliminary instructions to rear subunits. (16). Formulation of problems of rear subunits and organization of coop. (17). Organization of support/security/provision of combat operations of subunits. (18). Displacement into area of expectant positions. (19). Preparation of rear subsection for combat activities.

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In graph/curve (Fig. 31) zero event (0) indicates "attack order is obtained", fourteenth event (14) - "tank battalion to offensive is ready". Remaining events are intermediate and are the result of the execution of the corresponding works. For example, event (1) is the result of the execution of work (0, 1) indicates "problem to the offensive by the commander of tank battalion it is clarified", event (2) - "timing is produced", event (4) - "the warning orders to combat subunits are returned" and so forth.

In this graph/curve from above arrows/pointers are indicated designations of works, and below each arrow/pointer - their duration in minutes.

From preceding/previous material it is known that events, indicated in network graph, have no duration. Each event is the result of the previous work (or several works) and is achieved as instantly, as soon as the previous work or quite prolonged from the previous works will end, if them several, for example work (6, 9), which precedes event (9). Since the events do not have a duration, time of the termination of the preceding/previous work is the time of the beginning of the subsequent work.

Since battalion commander will begin work on organization of offensive after obtaining of attack order, let us accept the time of earliest accomplishment of initial (zero) event for zero. Zero event is a beginning of the work of battalion commander.

Operating time (0, 1), as can be seen from graph/curve, lasts 5 min, since event (1) will be achieved as soon as it will end work (0, 1) and it is in any way not earlier, earliest of possible periods of accomplishment of event (1) will be period, equal to 5 min. Event (2) will be achieved immediately after the termination of work (1, 2). Taking into account the circumstance/case/fact that the events do not

have a duration, the earliest period of the accomplishment of event (2) will be the total time of the duration of two preceding event (2) operations, namely: $t_{(0,1)}+t_{(1,2)}=5$ мин$+5$ мин $=10$ мин. So are determined the earliest periods of the accomplishment of events, which one work precedes.

If several works precede event in net/system, then earliest period of accomplishment of event will come only if preceding event works, which have greatest duration, will be achieved.

For example, let us determine earliest of possible periods of accomplishment of event (8) (Fig. 31). Event (8) precede two sequences/consistencies of works, namely: (0, 1) (1, 2) (2, 3) (3, 4) (4, 8) and (0, 1) (1, 2) (2, 3) (3, 5) (5, 8). Event (8) will be achieved only if all works, which precede this event, will be achieved. But these sequences/consistencies of the works (we will henceforth them call routes/paths) have different duration.

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Let us calculate the duration of these routes/paths:

the first path:

$$t_{(0,1)}+t_{(1,2)}+t_{(2,3)}+t_{(3,4)}+t_{(4,8)}=$$
$$=5+5+5+5+0=20 \text{ мин};$$

the alternate path:

$$t_{(0,1)}+t_{(1,2)}+t_{(2,3)}+t_{(3,5)}+t_{(5,8)}=$$
$$=5+5+5+15+60=90 \text{ мин.}$$

If all works, which lie on first path and which precede event (8), are achieved, then this event yet will not be achieved, since yet will not be completed works (3, 5) and (5, 8), that lie on alternate path. Event (8) will be achieved, as soon as these works will end. Consequently, the time, equal to 90 min after the beginning of process, will be earliest of the possible periods of the accomplishment of event (8).

Generalizing aforesaid above, it is possible to draw conclusion: time of early accomplishment of any event in net/system is equal to duration of maximum from routes/paths, which precede this event.

If we through $\bar{L}_1$ designate maximum on duration route/path, which precedes event (i), then rule given above can be expressed analytically:

$$t_{p(i)}=t(\bar{L}_{1(i)}). \qquad (7)$$

Taking into account that time of early termination of work (i, j) is time of earliest accomplishment of event (j), $t_{p(j)}$ it is possible to express through t_{i} and $t_{(i,j)}$. In this case we will have

$$t_{p(j)}=\max_{i}[t_{p(i)}+t_{(i,j)}]. \qquad (8)$$

Formula (8) can be read thus: most early time of occurrence of an event (j) is equal greatest of sums of earliest occurrence of an event (i) and durations of corresponding operations, which precede event (j).

It is completely understandable that in order to use formula (8), it is necessary to know time of offensive of initial event. In the majority of the cases it is convenient to consider that it is equal to zero, although in principle for it it is possible to establish nonzero value.

Summing up sum said, it is possible to conclude that minimally necessary time between offensive of initial and this events is time, which corresponds to movement of process (operation/process) along route/path of greatest duration of all routes/paths, which connect initial and this event. This time is measured by sum $t_{(i,j)}$ from the works, connected with the route/path, and is determined the earliest date of the offensive of this event.

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As can be seen from Fig. 31, network model of process

(net/system) encompasses number/series of sequences/consistencies of works. We named/called these sequences/consistencies routes/paths.

These routes/paths in network graph, shown in Fig. 31, and will bring together them and will examine in Table 4.

Interconnections between works are such, that each of such sequences/consistencies must be compulsorily observed. Although is intuitive this completely understandably however let us assume that in our net/system the sequence/consistency No. 10 is not observed, that will not make it possible to complete the task (3, 7) (7, 13) and (13, 14), as a result of which will not begin event (14), completion of entire complex. It is necessary to keep in mind that nonfulfillment by one of the works, connected with the net/system, leads to the nonfulfillment of entire operation/process.

Knowing duration of execution of each work individually, it is easy to determine duration of execution of each sequence/consistency on graph/curve by simple summation/totalling of indices/measures of time of duration of corresponding operations. It is possible to determine the length of each route/path, existing/available in the graph/curve, thus. Let us calculate the duration of routes/paths for our example (Table 5).

Earlier it was said, that observance of each sequence/consistency of works in our example is compulsory. Therefore entire complex of the work of the commander of battalion and its staff/headquarters on the organization of offensive cannot be completed earlier than after 170 min from the moment/torque of the beginning of works. Since the works in the graph/curve were calculated in the minutes, therefore, and entire complex of works in the net/system will engage 170 min. This will be the earliest period of the accomplishment of entire complex of works.

Each of ten sequences/consistencies of works, enumerated in network graph (Fig. 31), from initial to terminal event, is not another as route/path.

Table 4.

(1) Номер пути (последовательность работ)	(2) Работы, образующие путь (последовательность работ)
1	(0, 1), (1, 2), (2, 3), (3, 4), (4, 11), (11, 14)
2	(0, 1), (1, 2), (2, 3), (3, 4), (4, 8), (8, 11), (11, 14)
3	(0, 1), (1, 2), (2, 3), (3, 5), (5, 8), (8, 11) (11, 14)
4	(0, 1), (1, 2), (2, 3), (3, 5), (5, 9), (9, 12), (12, 14)
5	(0, 1), (1, 2), (2, 3), (3, 5), (5, 9), (9, 14)
6	(0, 1), (1, 2), (2, 3), (3, 5), (5, 10), (10, 13), (13, 14)
7	(0, 1), (1, 2), (2, 3), (3, 6), (6, 9), (9, 12), (12, 14)
8	(0, 1), (1, 2), (2, 3), (3, 6), (6, 9), (9, 14)
9	(0, 1), (1, 2), (2, 3), (3, 7), (7, 10), (10, 13), (13, 14)
10	(0, 1), (1, 2), (2, 3), (3, 7), (7, 13), (13, 14)

Key: (1). Number of route/path (sequence/consistency of works). (2). Works, which form route/path (sequence/consistency of works).

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Route/path quite prolonged on the time is called critical path. Consequently, the time of the end of the process, planned in the graph/curve, is determined by the length of critical path. About the routes/paths it will be in detail said below.

In our example, after finding most early time of accomplishment of terminal event (14), it is possible to determine length of critical path and, consequently, also to determine minimally necessary time, required for training of tank battalion for offensive with sequence/consistency accepted and operating time.

Thus, summing up sum said, it is possible to make following conclusion. During the calculation of the earliest time of the accomplishment of events it is necessary to count off time along the maximum route/path from the initial to this event. Determining the consecutively/serially early time of the accomplishment of events, they reach before the event terminal net/system. The most early time of the accomplishment of the terminal event determines earliest of the possible periods of the accomplishment of entire complex of works (operation/process).

For best understanding let us examine again based on specific example order/formation of definition/determination of earliest periods of occurrence of an event, and also time, necessary for termination of entire development (complex of works). Fig. 32 shows conditional graph/curve. Above the arrows/pointers the numerals, which show duration in the units of time, are set, let us assume in the hours.

Table 5.

(1) Номер пути (последовательность работ)	(2) Общая продолжительность пути в мин (последовательности работ)
1	$(0, 1) + (1, 2) + (2, 3) + (3, 4) + (4, 11) + (11, 14) = 5 + 5 + 5 + 5 + 60 + 20 = 100$
2	$(0, 1) + (1, 2) + (2, 3) + (3, 4) + (4, 8) + (8, 11) + (11, 14) = 5 + 5 + 5 + 5 + 0 + 60 + 20 = 100$
3	$(0, 1) + (1, 2) + (2, 3) + (3, 5) + (5, 8) + (8, 11) + (11, 14) = 5 + 5 + 5 + 15 + 60 + 60 + 20 = 170$
4	$(0, 1) + (1, 2) + (2, 3) + (3, 5) + (5, 9) + (9, 12) + (12, 14) = 5 + 5 + 5 + 15 + 15 + 30 + 0 = 75$
5	$(0, 1) + (1, 2) + (2, 3) + (3, 5) + (5, 9) + (9, 11) = 5 + 5 + 5 + 15 + 15 + 15 = 60$
6	$(0, 1) + (1, 2) + (2, 3) + (3, 5) + (5, 10) + (10, 13) + (13, 14) = 5 + 5 + 5 + 15 + 15 + 30 + 15 = 90$
7	$(0, 1) + (1, 2) + (2, 3) + (3, 6) + (6, 9) + (9, 12) + (12, 14) = 5 + 5 + 5 + 10 + 30 + 30 + 0 = 85$
8	$(0, 1) + (1, 2) + (2, 3) + (3, 6) + (6, 9) + (9, 14) = 5 + 5 + 5 + 10 + 30 + 15 = 70$
9	$(0, 1) + (1, 2) + (2, 3) + (3, 7) + (7, 10) + (10, 13) + (13, 14) = 5 + 5 + 5 + 5 + 0 + 30 + 15 = 65$
10	$(0, 1) + (1, 2) + (2, 3) + (3, 7) + (7, 13) + (13, 14) = 5 + 5 + 5 + 5 + 30 + 15 = 65$

Key: (1). Number of route/path (sequence/consistency of works). (2). General/common/total duration of route/path in min (sequence/consistency of works).

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Entering just as in the examination of graph/curve in Fig. 31, we will determine the early periods of the accomplishment of the events, which will appear by the following:

$$t_{p(2)} = t_{p(1)} + t_{(1,2)} = 0 + 7 = 7;$$
$$t_{p(3)} = t_{p(1)} + t_{(1,3)} = 0 + 8 = 8;$$
$$t_{p(4)} = t_{p(2)} + t_{(2,4)} = 7 + 1 = 8;$$
$$t_{p(5)} = t_{p(2)} + t_{(2,5)} = 7 + 9 = 16;$$
$$t_{p(6)} = t_{p(5)} + t_{(5,6)} = 16 + 11 = 27;$$
$$t_{p(7)} = t_{p(6)} + t_{(6,7)} = 27 + 4 = 31.$$

Then through formula (8) we find time of earliest accomplishment of event (6), when two routes/paths precede it, and we take greatest of sums of early occurrence of an event (i) and durations of corresponding operations $t_{(i,j)}$.

In our example earliest period of accomplishment of entire development (complex of works) will be equal to 31 unit of time, i.e., 31 h.

Let us further examine one additional example (Fig. 33), in which it is necessary to determine earliest periods of occurrence of an event and time of entire development.

Fig. 33 shows network model of complex of works and duration of each operation is indicated. Discussing just as in the preceding/previous examples, we will determine the earlier periods of occurrence of an event and the time, necessary for the entire development (entire complex of works), which is shown in Fig. 34. From the graph/curve it is evident that the time of entire development is 131.6 units of time.

After becoming acquainted with methods of definition/determination of early periods of accomplishment of events, let us examine method of definition/determination of most

permissible possible late $t_{n(i)}$ periods of accomplishment of events. Each event in the net/system must be achieved within such period that it would remain sufficiently time for the execution of all works, which follow after these events.

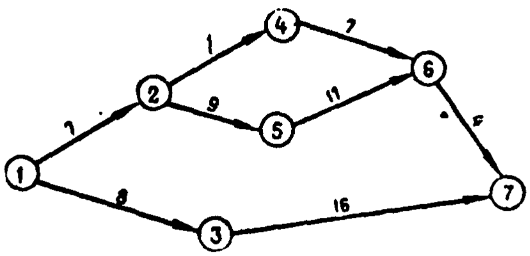

Fig. 32. Conditional network graph (example for the definition/determination of the earliest periods of the accomplishments of events).

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Let us turn again to graph/curve, given in Fig. 31, and let us examine event (9). This event must be achieved so that after its accomplishment would remain time for the execution of works (9, 12) and (12, 14). In order to find this time, it is necessary from the time of the accomplishment of the terminal event, which is characterized by the length of critical path, to deduct maximum route/path from those following after the given event (i) of routes/paths.

For event (9) maximumly subsequent there will be route/path (9, 12, 14). Consequently,

$$t_{n(9)} = t_{кр} - (t_{(9,12)} + t_{(12,14)}) = 170 - (30 + 0) = 140 \text{ мин.}$$

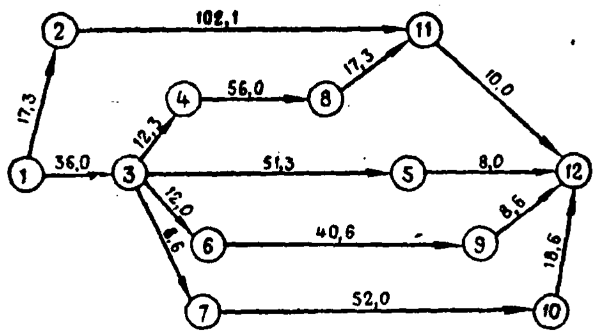

Fig. 33. Network model of the complex of works.

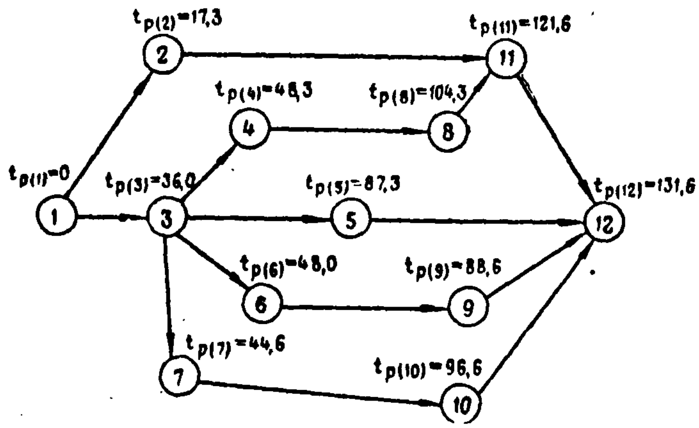

Fig. 34. Network model of complex of works with instruction of earliest periods of accomplishment of events and time, necessary for execution of entire development.

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This means that latest time of accomplishment of event (9) must not exceed 140 min after beginning of process. If this event is achieved later, then entire process will not be carried out within

the previously designed periods, i.e., during 170 min, periods will increase, moreover on as much, on will be as later ideal event (9).

If we designate through $\bar{L}_{2(i)}$ maximum subsequent after event (i) path, then given rule can be expressed by formula

$$t_{п(i)} = t_{кр} - t(\bar{L}_{2(i)}). \qquad (9)$$

Thus, late period of accomplishment of event is calculated as difference between duration of critical path and duration of maximum from subsequent after event (i) paths.

During calculation of time of latest permissible period of accomplishment of event they enter on the contrary, than during definition/determination of earliest period of accomplishment of event, namely calculation/crew is begun from terminal event and they go to initial event.

However, it is necessary to keep in mind that for events, which lie on critical path, time of early accomplishment of event $t_{p(i)}$ is equal to time of late accomplishment of event $t_{п(i)}$, $t_{p(i)} = t_{п(i)}$.

But now based on specific example (Fig. 35) let us determine late periods of accomplishment of events (8) (7) (6) and (3). The numerals above the arrows/pointers indicate days.

Let us determine length of critical path first, for which we enter as follows:

$$t_{\text{кр}} = t_{(1,2)} + t_{(2,4)} + t_{(4,6)} + t_{(6,7)} + t_{(7,8)} = \\ = 10 + 50 + 100 + 50 + 40 = 250 \text{ to days.}$$

Consequently, critical path is equal to 250 days. Then we find the time of the late accomplishment of terminal event (8). It is determined by critical path.

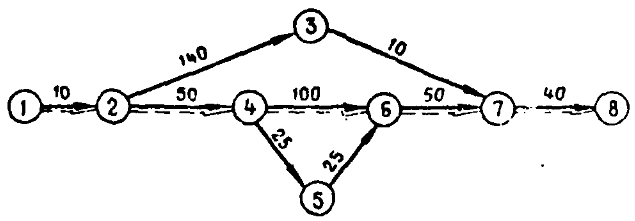

Fig. 35. Network graph (example) for the definition/determination of the time of the late accomplishment of events.

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But to us it is known that the time of the earliest accomplishment of terminal event $t_{p(8)}$ is equal to 250 days. But to us known also that the time of the earliest accomplishment of the completing events is equal to the time late accomplishment of terminal event $t_{n(8)}$, т. е.

$$t_{p(8)} = t_{n(8)} = 250 \text{ days.}$$

By then the same route/path we find time of late accomplishment of event (7):

$$t_{n(7)} = t_{кр} - t_{(7,8)} = 250 - 40 = 210 \text{ days.}$$

After this we find time of late accomplishment of event (6):

$$t_{п(6)} = t_{кр} - (t_{(7,8)} + t_{(6,7)}) = = 250 - (40 + 50) = 250 - 90 = 160 \text{ days.}$$

And finally, we determine time of late accomplishment of event (3):

$$t_{п(3)} = t_{кр} - (t_{(7,8)} + t_{(3,7)}) = = 250 - (40 + 10) = 250 - 50 = 200 \text{ days.}$$

Thus, in our example time (periods) of late accomplishment of events (8) (7) (6) and (3) are respectively equal to 250, 210, 160 and 200 days.

Definition/determination of the time of early beginning and termination of works.

Each event of network graph is simultaneously final event for some works and initial event for others. For example, on the graph/curve, shown in Fig. 31, event (3) is the end of work (2, 3) and by the beginning of works (3, 4) (3, 5) (3, 6) and (3, 7). Therefore, besides the early date of the offensive of this event, for the calculations/crews according to network graphs the time of the possible periods of early beginning and termination of works is determined also.

Time of early beginning of work $(t_{р.н(i,j)})$ is determined as

follows. Earlier has already been noted that the events do not have a duration. As soon as work ended, it is possible to consider that also was achieved the event. On the basis of this it is possible to assert that the time of the early beginning of work is equal to the time of the early accomplishment of event, i.e.,

$$t_{\text{p. н}(i,j)} = t_{\text{p}(i)} \qquad (10)$$

or, after replacing $t_{\text{p}(i)} = \max(t_{\text{p. н}(h,i)} + t_{(h,i)})$, we will obtain

$$t_{\text{p. н}(i,j)} = \max(t_{\text{p. н}(h,i)} + t_{(h,i)}). \qquad (10')$$

In Fig. 31 it earlier began, for example, works (2, 3) there will be equal to time of early accomplishment of event (2), i.e., $t_{\text{p. н}(2,3)} = t_{\text{p}(2)}$:

$$t_{\text{p}(2)} = t_{\text{p}(1)} + t_{(1,2)} = 5 + 5 = 10$$

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Since $t_{\text{p. н}(2,3)} = t_{\text{p}(2)}$, then $t_{\text{p. н}(2,3)} = 10$ min. This means that the earliest period of the beginning of work (2, 3) will be 10 min later than the beginning of process (operation/process).

Time of early termination of work $(t_{\text{p. о}(i,j)})$ is defined as sum of early time of accomplishment of event (i) and time of duration of operation itself (i, j). This can be expressed by the following formula

$$t_{p.o(i,j)} = t_{p(i)} + t_{(i,j)}.$$

Let us examine time of early termination of work (2, 3) (Fig. 31). Since the time of the early accomplishment of event (2) was determined earlier ($t_{p(2)} = 10$ min), we take operating time (2, 3) from the graph/curve. It is equal to 5 min. Consequently, the time of the early termination of work (2, 3) will comprise

$$t_{p.o(2,3)} = 10 + 5 = 15 \text{ min.}$$

This means that early time of termination of work (2, 3) can advance 15 min after beginning of process.

. But now based on one more example let us trace order/formation of definition/determination of time of early beginning and termination of works.

Fig. 36 gives graph/curve of simple operation/process, on which are shown works, their sequence/consistency and duration. Independently determine the time of early beginning and termination of each work and compare your decision/solution with the responses/answers, given in Fig. 37, where above each work these periods are indicated.

At beginning of each work time of its early beginning is written, while at end - time of early termination of work.

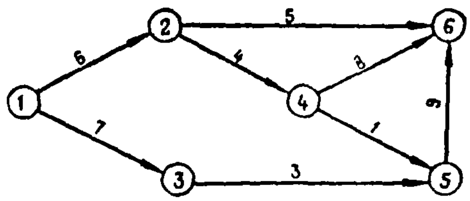

Fig. 36. Network model (example for the definition/determination of early beginning and early termination of works).

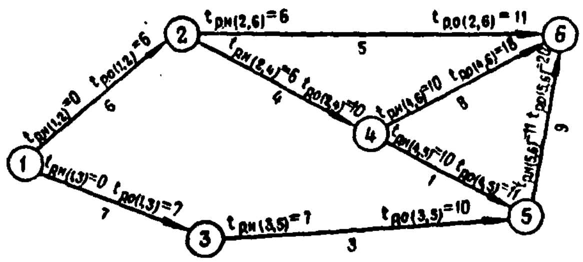

Fig. 37. Graph/curve with instruction of time of early beginning and early termination of works.

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Definition/determination of critical path.

We have already been introduced to definition/determination of concept of route/path. Let us recall that in any network graph each of the sequences/consistencies from the initial event to that completing is route/path. Such routes/paths there can be much and on their duration they can be different. However, in network planning

special position is assigned to the so-called critical path.

Critical path - this is quite prolonged on time route/path in network graph from initial to terminal event. When they speak "quite prolonged route/path in the net/system", then one should clearly understand that this nevertheless minimally necessary time, objectively required for the realization of entire complex of the works, entering the net/system. For the shorter time than the time of critical path, entire complex of works objectively cannot be achieved.

Why is it called critical? This is explained by two reasons. First, precisely this route/path by nature in the network graph determines the duration of the accomplishment of entire complex of works. In the second place, term "critical path" is intended to draw attention to this group, to this chain/network of works. Specifically, that sequence/consistency of the works, which lie/rest by this method, determines course of events (process, the complex of works, development). If delay on other works, which do not lie on critical path, cannot affect in the principle the execution of entire process as a whole, then any delay on the work of critical path will increase its duration, and also, therefore, increases the time of the execution of entire process.

Consequently, calculation/crew graph/curve and development/detection of critical path are necessary in order to concentrate attention precisely in critical chain/network of events. Network graph not only requires this, but also gives the capability to see this route/path. Critical path - this exactly and there is the component/link in the general/common/total net/system of complicated interconnections, after being grasped for which, it is possible to take out entire net/system. The positive properties of critical path consist in the practical application/appendix of the idea of the leading component/link to the leadership/manual of complicated processes.

Principle of concentration of attention and resources/service lives in decisive/key sectors/directions and sectors of works in critical periods of execution of combat tasks/missions is familiar. However, with the traditional practice the commands of troops the selection of such sectors, and also moment of time are realized by intuition, according to the experience of command. In this case no model of process is examined.

However, network graphs are complex model of operation/process, conducted in completely specific conditions and which requires specific forms of resources/service lives and time. This model reflects/represents the specific features of entire operation/process

(development) in the interdependence and interconditionalities.

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Idea indicated above of the leading component/link in the general/common/total net/system of events and works obtains completely clear characteristic curve here.

Development/detection of critical path, and consequently, development/detection of events and works, which lie by this method, makes it possible to concentrate attention first of all precisely at critical works and events, which determine duration of operation/process (process), but not to disperse attention in entire mass of events and works, entering net/system. In reality, if we turn to Fig. 31, then it is possible to see that of all 14 events on the critical path lie/rest only 8 events (0, 1, 2, 3, 5, 8, 11 and 14), and from the total quantity of 22 works on critical path lie/rest only 7 works (0, 1; 1, 2; 2, 3; 3, 5; 5, 8; 8, 11; 11, 14).

It is completely understandable that in this case to more easily follow only events and works, which lie on critical path. This is especially important, when in the planned/glide operation/process there are very many works.

Experience/experiment/lesson established/installed, that, the more complicated processes (operations/processes), the less specific weight/density of critical works, which helps to concentrate attention on main component/link of works.

Table 6 gives specific weight/density of critical works in operations/processes of different complexity.

Critical path is found as a result of calculation/crew of entire net/system, definition/determination of events earliest of possible periods of accomplishment and works. As soon as the most early time of the accomplishment of latter/last work will be found, and therefore, and the terminal in the net/system event, then will be determined the earliest period of the accomplishment of entire operation/process (development), i.e., the critical period of development will be determined.

If we turn to graph/curve (Fig. 31), then let us see ten sequences/consistencies of works on it. Each of these sequences/consistencies is nothing else but route/path. the durations of all routes/paths were calculated. Route/path of 3 (Table 5) proved to be most prolonged. Its duration is 170 min. This is a critical path of this net/system. However, this duration of training battalion for the offensive cannot satisfy, since on the given conditions battalion must be ready to the offensive for 2 h 10 min, i.e., after 130 min.

Table 6.

(1) Общее количество работ в сети	(2) Количество критических работ	(3) Удельный вес критических работ, %
10	3–4	30–40
100	12–15	12–15
1000	70–80	7–8
5000	150–160	3–4

Key: (1). Total quantity of works in the net/system. (2). Number of critical works. (3). Specific weight/density of critical works, %.

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Consequently, it is necessary to change operational procedure on training of battalion for the offensive in order to shorten critical path 40 min. Procedure and order/formation of an improvement in the net/system will be examined in the following chapter.

It is necessary to have in mind that in one net/system there can be several critical paths. Sometimes in the nets/systems critical path can branch by several routes/paths and again pour into one.

Thus, critical path is characterized by two characteristics, which play important role during analysis of complex of works:

- for transition/transfer from initial event to that completing

along critical path is spent greatest time;

- delay in offensive of any event, which lies on critical path, is caused accurately the same delay in offensive of terminal event.

All other total/full/complete routes/paths, except critical ones, are called non-critical paths. In turn these non-critical paths are divided into the subcritical routes/paths and the routes/paths, which possess the large reserve of time.

Routes/paths, close in their duration to critical ones, are called subcritical. Subcritical routes/paths are characteristic fact that while conducting of number/series of the measures, which can entail the reduction of critical paths, subcritical routes/paths can become critical.

Experience/experiment/lesson of use/application of network planning and control shows that in sphere of control always should be kept also subcritical routes/paths. In the case of exceptional attention only to the critical paths and neglect to the subcritical routes/paths the probability of the unjustifiably large bracing of the periods of the performance of works out of the critical path becomes large. This tightening of works along the routes/paths, little different from the critical ones, can change situation, and

critical path can become the subcritical route/path, on which occurred the delay of works.

Concentration of attention in critical and subcritical paths will make it possible to foresee, to forecast appearance of bottlenecks and disruptions/separations in works in course of the process.

Subcritical routes/paths possess small reserve of time.

Non-critical paths, which possess large reserve of time, are characterized by fact that from these routes/paths it is possible to remove/take resources/service lives (for example, technical means/equipment) and to move them to critical paths in order to accelerate on them works thereby to shorten time of critical paths and, consequently, also entire process as a whole. This exactly is the main thing in network planning, since it makes it possible to maneuver with internal reserves and resources/service lives and thereby to strive the acceleration of the accomplishment of process (operation/process), without resorting to the use of forces, means/facilities and resources/service lives from without.

Now based on specific example let us trace order/formation of definition/determination of critical path.

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Fig. 38 shows the network graph of the complex of works, on which are shown the works, their duration and sequence/consistency, and also three routes/paths. Analyzing graph/curve, it is possible to determine the duration of each route/path, namely:

- for route/path of No 1 $t_{(1,2)}+t_{(2,5)}=7+16=23;$

- for route/path of No 2 $t_{(1,3)}+t_{(3,5)}=21+4=25;$

- for route/path of No 3 $t_{(1,4)}+t_{(4,5)}=3+17=20.$

Critical path is route/path most prolonged on time. Consequently, in our example critical path $(t_{кр})$ is equal to 25 and it passes through events (1) (3) (5) (Fig. 39).

Let us attempt to again find critical and subcritical paths on graph/curve, shown in Fig. 40.

In Fig. 40 only of five routes/paths. Analyzing graph/curve and determining the duration of the sequences/consistencies of works, we

will obtain the following picture:

- for route/path of No 1 $t_{(1,2)}+t_{(2,6)}+t_{(6,8)}=2+7+10=19;$

- for route/path of No 2 $t_{(1,3)}+t_{(3,5)}+t_{(5,6)}+t_{(6,8)}=9+12+3+10=34;$

- for route/path of No 3 $t_{(1,3)}+t_{(3,5)}+t_{(5,7)}+t_{(7,8)}=9+12+3+10=34;$

- for route/path of No 4 $t_{(1,4)}+t_{(4,5)}+t_{(5,6)}+t_{(6,8)}=8+4+3+10=25.$

- for route/path of No 5 $t_{(1,4)}+t_{(4,5)}+t_{(5,7)}+t_{(7,8)}=8+4+3+10=25;$

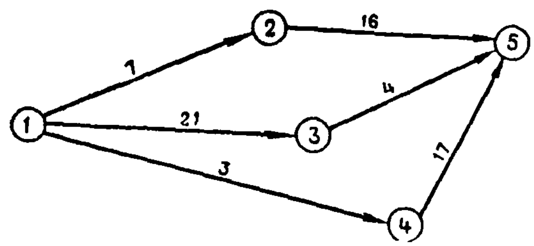

Fig. 38. Example for the definition/determination of critical path on the graph/curve.

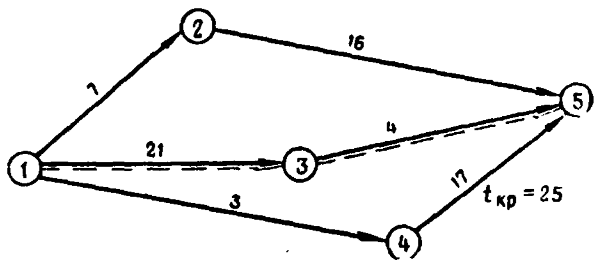

Fig. 39. Result of deciding/solving problem, represented in Fig. 38.

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As can be seen from calculation/crew, on graph/curve (Fig. 41) there are two critical paths:

- route/path No 2, passing through events (1) (3) (5) (6) (8);

- route/path No 3, passing through events (1) (3) (5) (7) (8).

On the same graph/curve it is shown even two subcritical

routes/paths:

- route/path No 4, passing through events (1) (4) (5) (6) (8);

- route/path No 5, passing through events (1) (4) (5) (7) (8).

Thus, solving problem, placed on graph/curve (Fig. 40), were obtained two critical and two subcritical paths, therefore, in one graph/curve there can be several critical and subcritical paths.

Definition/determination of the late permissible periods of beginning and termination of works.

Let us recall that on network graph (Fig. 31) beginnings of works early from possible periods were determined consecutively/serially from initial (zero) event to terminal (fourteenth) event. In this case they used formulas (10) and (8).

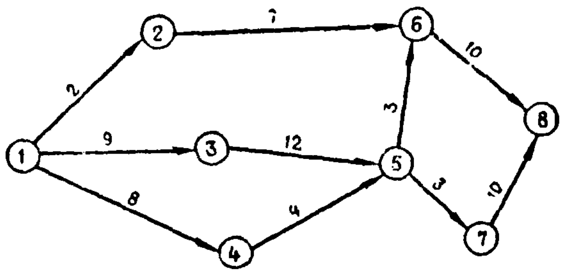

Fig. 40. Conditional network graph (example for the definition/determination of critical and subcritical paths).

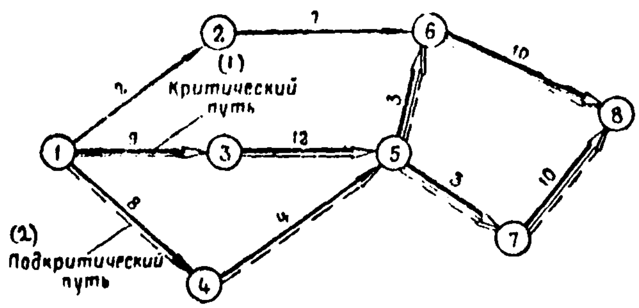

Fig. 41. Result of deciding/solving problem, placed in Fig. 40.

Key: (1). Critical path. (2). Subcritical route/path.

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After determining early period of beginning of terminal (fourteenth) event, let us establish/install critical path and time of accomplishment of entire process. All other routes/paths are shorter than the critical. If we from these routes/paths remove/take

resources/service lives and to move them to the critical path, then it is possible to attain shortening its duration. Of course in this case it is tightened the chain/network of the works, from which removed/took the resources/service lives. However, it is necessary to keep in mind that so that the routes/paths, from which are taken/removed the resources/service lives, would not be expanded excessively and any other route/path did not become longer (prolonged) than the initially designed critical path. It is obvious, it is necessary to maintain/withstand some limit of magnification in the route/path. For this the concept and the index/measure of the latest permissible period of beginning and termination of works are utilized. This index/measure is designated by symbol $t_{n(i)}$, where i - number of event, according to which is determined the index/measure. The sense of this index/measure consists in the fact that it designates the period, beyond limits of which to inadmissibly draw off the execution of the works, which converge to the specific event. If work is drawn off beyond limits $t_{n(i)}$, then this indicates the delay of the completion of entire process.

It is completely understandable that $t_{n(i)}$ is connected with events, and, first of all, with terminal event of net/system. After the early time of the accomplishment of the terminal event is determined, it becomes obvious, that for the terminal event the time of early and the time of late accomplishment must be equally, i.e.

$t_{\text{п}(n)} = t_{\text{р}(n)}$ This assumption is logical, since there is no sense immediately to establish that work it is tightened over the period of the terminal event.

Knowledge of earliest and latest permissible period of occurrence of an event makes it possible to isolate those, which lie/rest on critical path of them. The events, most early time and the most late time of offensive of which coincides, are located on the critical path. The arrows/pointers, which connect these events, correspond to the critical sequence/consistency of works.

It was already established/installed, that each work originates early and early termination. Similar to this each work can originate late and late termination.

Thus, it is possible to say that periods of late beginning and late termination of work are determined by back stroke from terminal event to initial, i.e., from right to left.

Periods of late beginning of work $(t_{\text{п.н}(i,j)})$ are defined as difference in its late termination $(t_{\text{п.о}(i,j)})$ and duration of operation itself $(t_{(i,j)})$:

$$t_{\text{п.н}(i,j)} = t_{\text{п.о}(i,j)} - t_{(i,j)}. \qquad (11)$$

Taking into account that late termination of this work is late beginning of subsequent work, i.e., $t_{п.о(i,j)}=t_{п.н(j,k)}$, formula (11) can be represented in dide

$$t_{п.н(i,j)}=t_{п.н(j,k)}-t_{(i,j)}. \qquad (12)$$

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Let us take graph/curve (Fig. 31) and it is determined late beginning, for example, of work (11, 14). To us it is already known that the time of the early accomplishment of the terminal event and all events, which lie on the critical path, is equal to the time of the late accomplishment of these events, i.e., $t_{р(i)}=t_{п(i)}$. The periods of early beginning and late termination of event (14) will come as soon as it will end work (11, 14), which lies on the critical path. But this work, as to us it is known, will end 170 min after the beginning of process. Consequently, the period, equal to 170 min after the beginning of works, will be the latest period of the termination of work (11, 14). The duration of operation (11, 14) is equal to 20 min. Substituting 20 min into formula (11), we will obtain

$$t_{п.н(11,14)}=t_{п.о(11,14)}-t_{(11,14)}=170-20=150 \text{ min.}$$

This means that work (11, 14) must be begun not later than 150 min after beginning of process. If it is begun more lately, then

entire process will not lie/fall/lay in the estimated time, i.e., it will exceed the period, equal to 170 min.

Periods of late termination of work ($t_{п.о(i,j)}$) are determined on periods of late beginning of subsequent work, i.e., they are equal to them:

$$t_{п.о(i,j)} = t_{п.н(j,k)}. \tag{13}$$

Let us take, for example, work (8, 11) let us determine period of its late termination (Fig. 31). The period of the late beginning of work (11, 14) was determined above. It is equal to $t_{п.н(11,14)} = 150$ min. But since work (11, 14) is with respect to work (8, 11) of that following, i.e. work (j, k), the late termination of the preceding it work, i.e., work (8, 11), it is equal to the late beginning of work (11, 14). Consequently,

$$t_{п.о(8,11)} = t_{п.н(11,14)} = 150 \text{ min.}$$

If is determined period of late termination of work, after which several works go, then period of late termination of this work will be equal to minimum value of all subsequent works:

$$t_{п.о(i,j)} = \min t_{п.н(j,k)}. \tag{14}$$

For example, let us take graph/curve (Fig. 31) and is determined

period of late termination of work (6, 9). For this let us determine the periods of the late beginning of the works, which follow after event (9), i.e., works (9, 12) and (9, 14):

$$t_{\text{п. н}(9,12)} = t_{\text{п. о}(9,12)} - t_{(9,12)} = 170 - 30 = 140 \text{ мин}^{(1)};$$
$$t_{\text{п. н}(9,14)} = t_{\text{п. о}(9,14)} - t_{(9,14)} = 170 - 15 = 155 \text{ мин}^{(1)}.$$

Key: (1). min.

Since minimum value of period of late beginning of works, which follow at work (6, 9), is equal to 140 min, then let us take this minimum value.

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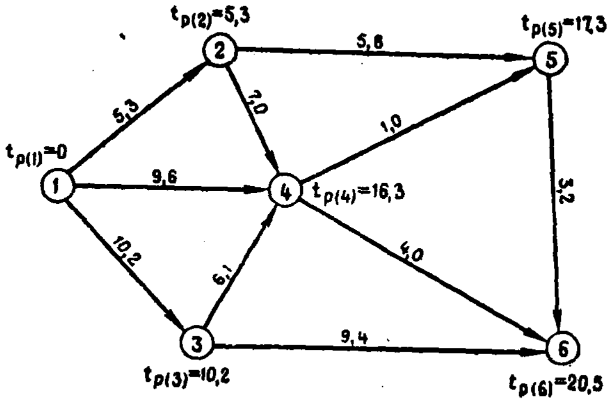

Fig. 42. Network model of complex of works (example for definition/determination of periods of late beginning and termination of works).

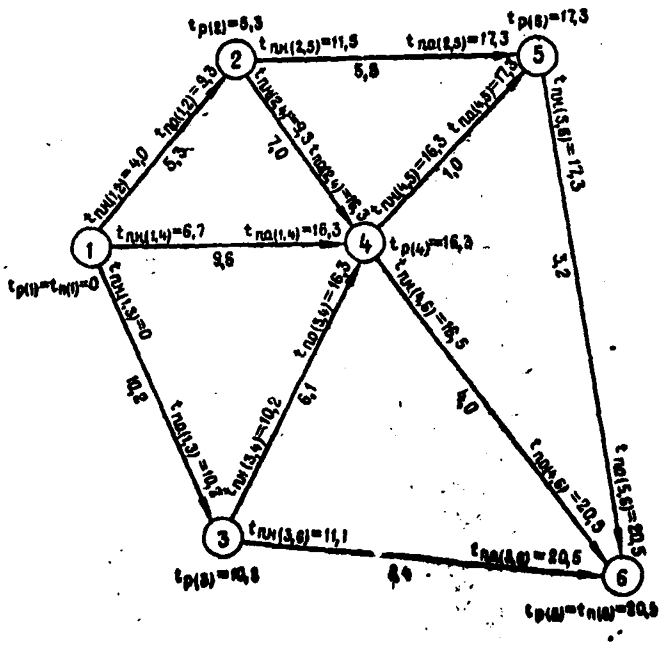

Fig. 43. Graph/curve with results of deciding/solving problem,

represented in Fig. 42.

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Substituting in formula (14) of value $t_{п.н(9,12)}$ and $t_{п.н(9,14)}$, we take of them minimum:

$$t_{п.о(6,9)} = \min(t_{п.н(9,12)};\ t_{п.н(9,14)}) = \min(140;\ 155) = 140 \overset{(1)}{мин}.$$

Key: (1). min.

Thus, work (6, 9) must end not later than 140 min after beginning of process, otherwise it can produce lengthening entire planned/glide operation/process.

Knowing procedure of definition/determination of periods of late beginning and termination of works, let us find these parameters in network graph, represented in Fig. 42.

Using formulas (11) and (13), let us determine periods of late beginning and late termination of each work, shown on graph/curve (Fig. 42). As a result we will obtain data, which are given on the graph/curve, shown in Fig. 43.

Calculation of the reserves of the time of events, works and

routes/paths.

In any network graph all non-critical paths, events and works, which lie not on critical paths, possess reserves of time. Development/detection and use of these reserves is the basic idea of network planning, since from the works and the routes/paths, which have the reserves of time, it is possible to remove/take human and material resources and to direct them for the execution of the works, which lie on critical paths. By this very it is possible to attain shortening the periods of performing critical work and, consequently, also entire operation/process, without resorting to the enlistment of resources/service lives from without, utilizing only internal reserves and resources/service lives and maneuvering with them.

For best understanding of question of definition/determination of reserves for routes/paths, events and works let us take initial net/system (Fig. 31) and, utilizing knowledge, obtained as a result of studying preceding/previous material, let us present it with already calculated periods of early and late accomplishment of events, periods of early and late beginning and termination of works. In this case let us write the periods of the early and late accomplishment of events next to the circles, which designate events; the operating time let us point out from below in the middle of each arrow/pointer; from above the arrows/pointers let us show: in the

beginning - periods of early and late beginning, at the end - periods of the early and late termination of works.

Fig. 44 shows initial network graph of training tank battalion for offensive from position/situation of direct contact with the enemy with designed periods. Now it is possible to examine the net/system of our graph/curve with the calculated temporary/time estimations/evaluations of events and works.

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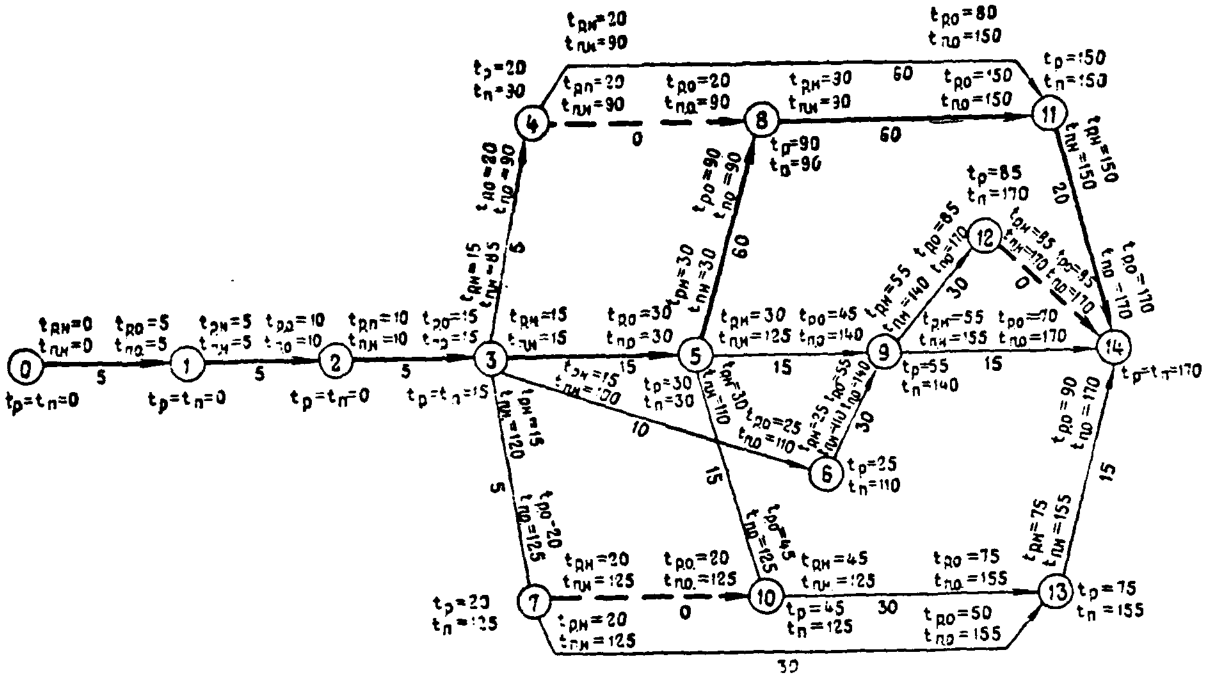

Fig. 44. Initial network graph of preparation of tank battalion to offensive with designed parameters.

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Determination of the total reserve of the time of route/path.

It was above noted that length of critical path is more than length of any route/path of network graph. The difference between the length of critical path $t_{кр}$ and the length of any route/path $t_{(L)}$ is called the total/full/complete reserve of time $(P_{(L)})$ of this route/path and is determined from the formula

$$P_{(L)}=t_{кр}-t_{(L)},$$

where $P_{(L)}$ - total/full/complete reserve of the time of route/path;

$t_{(L)}$ - length of any route/path.

Let us determine total/full/complete reserve of time of route/path of 0, 1, 2, 3, 7, 10, 13, 14 in graph/curve (Fig. 44). For this let us calculate the length of this route/path:

$t_{(0,1)}+t_{(1,2)}+t_{(2,3)}+t_{(3,7)}+t_{(7,10)}+t_{(10,13)}+t_{(13,14)}$=5+5+5+5+0+30+15=65 min.

Length $t_{кр}=170$ min, therefore,

$$P_{(L)}=t_{кр}-t_{(L)}=170-65=105 \text{ min.}$$

The less any route/path in comparison with critical path, the greater it has total/full/complete reserve of time.

Total/full/complete reserve of time of route/path is shown, on how much in sum can be increased duration of all operations, which belong to route/path of L, without essential effect on general/common/total period of process. In other words, total/full/complete reserve of time of this route/path $P_{(L)}$ is shown the maximum permissible increase in the length of this route/path $t_{(L)}$. Even if we further increase $t_{(L)}$, then critical path will move for this route/path.

Total/full/complete reserve of time of route/path is general/common/total for all works of corresponding sector. This should be understood thus: if the longest noncritical route/path nowhere interesects the critical (except initial and terminal events), then it determines reserve of the analyzed events. Moreover the quantity/magnitude of reserve is general/common/total for all these events and is equal to a difference in the critical and noncritical paths.

If route/path being investigated interesects critical, then

total/full/complete reserve of time of route/path is determined on individual noncritical sectors. In this case the grouping of events on the reserve general/common/total for them is possible only such, that these events are arranged/located in the sectors, locked between the pair of the events of critical path. Then general reserve is determined by the quite prolonged sector, which passes on them. This quite prolonged route/path will consist of the sector of the critical path, which precedes this sector, from this sector and from the subsequent sector of critical path.

Thus, let us generalize: total/full/complete reserve of time of route/path can be defined as reserve, which belongs to noncritical sector of route/path, locked between two events of critical path, and being general/common/total for works of this sector.

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Definition/determination of the reserves of the time of events.

Reserve of time of event $P_{(i)}$ is called difference between time of late and time of early accomplishment of this event:

$$P_{(i)} = t_{п(i)} - t_{р(i)}.$$

As can be seen from graph/curve (Fig. 44), value of time of

early ($t_{p(i)}$) and to time of late ($t_{n(i)}$) accomplishment of events, which lie on critical path, are equal. For example: for event (1) $t_{p(1)}-t_{n(1)}=5$; for event (3) $t_{p(3)}=t_{n(3)}=15$; for event (5) $t_{n(5)}-t_{n(5)}=30$ for event (14) $t_{p(14)}=t_{n(14)}=170$.

This means that events of critical path do not have reserves of time. Equality $t_{p(i)}=t_{n(i)}$ is one of the signs/criteria of critical path. Besides this, in the works, which lie on critical path earlier and late beginning and earlier and their late termination they coincide. This means that and these works also do not have reserves of time.

As far as events, which lie not on critical paths, are concerned, in them is specific difference between time of early and late accomplishment, i.e., between $t_{p(i)}$ and $t_{n(i)}$. For example, for event (9) $t_{p(9)}=55$ min, and $t_{n(9)}=140$ min. As is evident, here there is the difference: 140-55=85 min. This difference means that event (9) can advance on 85 min later than the early accomplishment of this event $t_{p(6)}$ and this in no way will influence the completion of the process of training tank battalion for the offensive.

If we will represent that real period of occurrence of an event with any arbitrary number (i) is designated through $t_{л(i)}$, then must, obviously, be observed dependence $t_{p(i)} < t_{л(i)} < t_{n(i)}$, whereas for events, which lie on critical paths, must be observed equality $t_{p(i)}=t_{л(i)}=t_{n(i)}$. If

this condition will be disrupted, i.e., if it occurs, that $t_{p(i)} = t_{n(i)} < t_{1(i)}$, then this will lead to the delay of works and to the disruption/separation of the periods of process as a whole.

Definition/determination of the reserves of operating time.

Earlier it was established/installed, that reserve of time of route/path $P_{(L)}$ can be used for increase in duration of operations, which are located by this method. Therefore it is possible to assert that any of the work of route/path L in its sector, which does not coincide with the critical path, possesses the reserve of time. The reserve of operating time, determined with the aid of the quantity/magnitude of the reserve of the time of route/path, on which it is located, it is called the total/full/complete reserve of operating time (i, j) and is designated through $P_{n(i,j)}$.

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From graph/curve (Fig. 44) it is evident that work (3, 5) can belong to several routes/paths. This means that through work (3, 5) it can pass several different routes/paths. Since the lengths of these routes/paths, as a rule, are not equal, then consequently, will be different the reserves of time in these routes/paths.

Total/full/complete reserve of operating time is defined as reserve of time of maximum route/path, passing through this work. The reserve of the time of any route/path can be distributed between the individual works, which are located on the route/path indicated, only in the limits of the total/full/complete reserves of the time of these works.

Quantity/magnitude $P_{п(i,j)}$ shows, to what period can be increased duration $t_{(i,j)}$ of individual operation (i, j), so that in this case length of maximum route/path $t_{(i,max)}$ passing through this work, would not exceed length of critical path.

Works, which lie on critical paths, do not have reserve of time, i.e., $P_{п(i,j)}=0$.

Let us examine formation/education of reserves for works based on specific example.

From Fig. 44 it is evident that time of early and time of late accomplishment of works is connected with events and at the same time offensive of time of early and late accomplishment of works is connected with very operation, which begin and which end in appropriate events. Hence it follows that, where it is possible to move aside certain event, without moving aside the period of the

accomplishment of works, there is the specific reserve of time.

Let us examine this in more detail, for which let us make table, in which let us show numerical value of difference between $t_{n(i)}$ and $t_{p(i)}$ each event (table 7).

In our example of seven events have difference between $t_{n(i)}$ and $t_{p(i)}$. This means that only these events can be moved, without affecting the periods of the completion of process. However, all these events, if we look to the graph/curve, carry the complicated character: in each of these events it converges/meets and diverge several works. Taking into account this, let us trace how difference $t_{n(i)}$ and $t_{p(i)}$ makes it possible to shift/shear or to dilate/extend the periods of the execution of work.

Table 7.

Таблица 7

(1) Событие	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
$t_{п(i)}$	0	5	10	15	90	30	110	125	90	110	125	150	170	155	170
$t_{р(i)}$	0	5	10	15	20	30	25	20	90	25	45	150	85	80	170
$t_{п(i)}-t_{р(i)}$	0	0	0	0	70	0	85	105	0	85	80	0	85	75	0

Key: (1). Event.

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For this let us examine several groups of works, existing/available in net/system, shown in Fig. 44.

First group - works, which lie on critical path. These works are shown on the graph/curve by heavy arrows. Let us enumerate them: (0, 1); (1, 2); (2, 3); (3, 5); (5, 8); (8, 11); (11, 14). Let us examine work (3, 5), whose content compose estimate of situation and decision making. it has initial event (3) and final - (5). If we for this work analyze the early and late periods of beginning and end, then we will see, that the time of early beginning is equal to the time of the late beginning of work, i.e. $t_{р.н(3,5)} = t_{п.н(3,5)} = 15$ and the time of early termination is equal to the time of the late termination of work, i.e., $t_{р.о(3,5)} = t_{п.о(3,5)} = 30$. Consequently, here it is not possible to make

a shift/shear in the work, because there is no reserve of operating time.

Thus, critical works just as critical events, do not have reserves of time.

Given resources/service lives and values based on this distribution of operating time $t_{(i,j)}$ compose basis of these works. For the critical works the analysis of shift/shear and change in the duration is clear: it is desirable to reduce these works in order to achieve the reduction of entire process as a whole. To shift/shear the events of critical path is possible only due to the supplementary resources/service lives from without or due to the enlistment from other work of this net/system. This can be made either in the stage of planning or in the course of the execution of the process of works.

Second group - works, which are located in net/system, for which neither initial nor final event belongs to events of critical path. Such works in our net/system (Fig. 44) five, namely: (6, 9); (9, 12); (7, 10); (7, 13) and (10, 13). The analysis of these works gives the capability to establish/install the presence of the free reserve of operating time (in the literature it it is occasionally referred to as the independent reserve of operating time).

Free reserve of operating time $(P_{c(i,j)})$ is formed when operating time is less than difference between earliest of possible periods of accomplishment of final event and latest of permissible periods of accomplishment of initial event of this work. Fig. 45 schematically shows this position/situation.

As can be seen from Fig. 45, free reserve is calculated from formula

$$P_{c(i,j)} = t_{p(j)} - t_{n(i)} - t_{(i,j)}$$

and condition of emergence of this reserve following: $t_{p(j)} - t_{n(i)} > t_{(i,j)}$, free reserve under condition $t_{p(j)} - t_{n(i)} < t_{(i,j)}$ does not appear.

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Free reserve for work shows that it is possible to increase operating time by quantity/magnitude of its free reserve, without affecting periods of accomplishment of its initial and final events and quantity/magnitude of reserves of time in all remaining work of net/system.

It is necessary to keep in mind that during calculation of free reserve of formula (17) results can prove to be negative. This will

indicate a deficiency/lack in the time. In effect/virtually negative values do not have sense; therefore calculate free stored up time one should only for those works, which actually/really have it. This, as a rule, is realized via selection the value between zero and by positive value, in other words by calculation/crew max 0, $t_{p(j)} - t_{n(i)} - t_{(i,j)}$.

Third group - works, which by their termination or with beginning are connected with critical path. These works make it possible to reveal/detect the local reserves of operating time. The local reserves for works are formed in the points of the intersection of routes/paths with the different duration and appear in the works, which belong to the routes/paths of smaller duration.

Local reserves are of two forms. Let us e amine this with the aid of the diagram/plan/circuit, shown in Fig. 46.

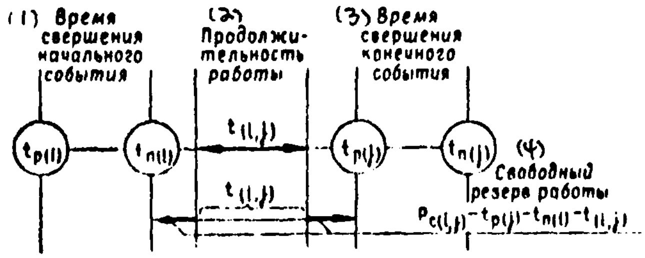

Fig. 45. Diagram/plan/circuit of the formation/education of the free reserve for work.

Key: (1). Time of the accomplishment of initial event. (2). Operating time. (3). Time of accomplishment of final event. (4). Free reserve for work.

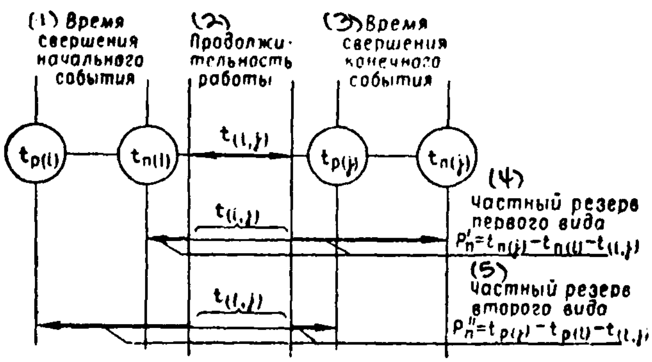

Fig. 46. Diagram/plan/circuit of formation/education of particular reserves of works.

Key: (1). Time of the accomplishment of initial event. (2). Operating time. (3). Time of accomplishment of final event. (4). Local reserve

of first form. (5). Local reserve of second form.

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Local reserve of first form $(P'_{n(i,j)})$ is formed in works, which follow after events, from which diverge routes/paths of different duration (Fig. 47). This reserve shows what unit of the total/full/complete reserve of operating time can be turned on an increase in the duration of this and other, subsequent after it operations, which belong to the route segment, included between two nearest points of intersection of its with the routes/paths of larger length when, if increase causes shortening the reserves of time not in one of the previous works.

In military affairs local reserve of first form $P'_{n(i,j)}$ can also be considered as index/measure of time, to which this work can be initiated earlier than planned period, without affecting final period of execution of entire operation/process.

Local reserve of first form, as can be seen from Fig. 46 and 47, it is calculated from formulas:

$$P'_{n(i,j)} = t_{n(j)} - t_{n(i)} - t_{(i,j)}$$

or

$$P'_{n(i,j)} = P_{n(i,j)} - P_{(i)},$$

Local reserve of second form $(P''_{\text{п}(i,j)})$ is formed in works, which directly precede event, in which are crossed/intersected routes/paths of different length (Fig. 48).

This reserve shows what unit of total/full/complete reserve temporary service it can be used on increase in duration of this and preceding it operations, which belong to route segment, included between two nearest points of intersection of its with routes/paths of larger length, when this increase will cause shortening reserves of time not in one of subsequent works.

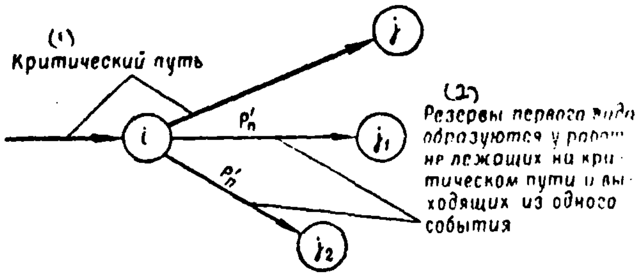

Fig. 47. Diagram/plan/circuit of the formation/education of the reserves of the first form.

Key: (1). Critical path. (2). Reserves of first type are formed in works, which do not lie on critical path and which come out of one event.

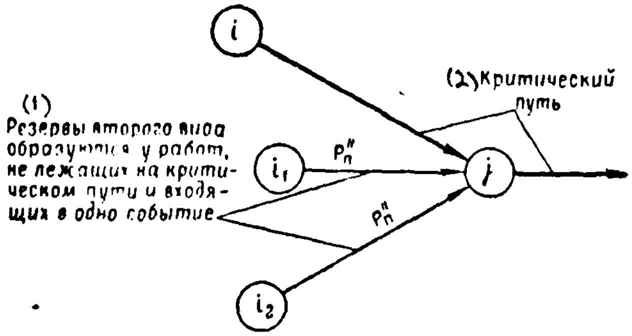

Fig. 48. Diagram/plan/circuit of the formation/education of the reserves of the second form.

Key: (1). The reserves of the second form are formed in the works, which do not lie on critical path and entering one event. (2). Critical path.

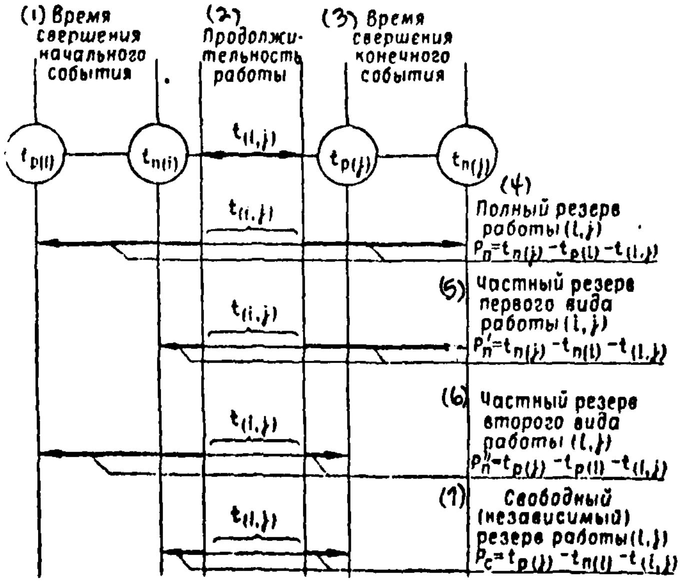

Fig. 49. Compound general diagram of formation/education of reserves for works.

Key: (1). Time of the accomplishment of initial event. (2). Operating time. (3). Time of accomplishment of final event. (4). Total/full/complete reserve for work. (5). Local reserve of first type of work. (6). Local reserve of second type of work. (7). Free (independent) reserve for work.

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In military affairs local reserve of second form $P'_{\text{п}(i,j)}$ can also be considered as index/measure of time, to which this work can be initiated later than planned period, without affecting final period of execution of entire operation/process.

Local reserve of second form, as can be seen from Fig. 46 and 48, is determined from formulas:

$$P'_{\text{п}(i,j)} = t_{\text{р}(j)} - t_{\text{р}(i)} - t_{(i,j)} \qquad (20)$$

or

$$P'_{\text{п}(i,j)} = P_{\text{п}(i,j)} - P_{(j)} \qquad (21)$$

Thus, reserves of time of routes/paths, events and works are necessary in order to improve initial plans/layouts, to conduct

monitoring/checking of works and to forecast works on the basis of their actual condition and predicted changes.

For the purpose of generalization of material on reserves of operating time let us make overall diagram of all forms of reserves for works so that they could be forseeable in one place. This will make it possible to better memorize the diagrams/plans/circuits of the formation/education of the reserves for works. Thus, for the work with the initial event (i) and the final event (j) the reserves of operating time are determined according to the diagram/plan/circuit, shown in Fig. 49.

Definition/determination of the coefficient of the intensity/strength of works.

During calculation/crew of network graphs it is important to know characteristic of intensity/strength of periods of execution of works. The quantity/magnitude of the coefficient of the intensity/strength of works, equal to the relation/ratio of duration, is this characteristic that are noncoincident and included between one and the same events of the route segments, one of which is the route/path of maximum duration, passing through this work, and the other - critical path.

If duration of section/segment of critical path is designated through $t'_{кр(L)}$, that coincides with route/path $L'_{(i)\max}$, and extent of maximum route/path - through $t_{(L)\max}$, passing through this work, then coefficient of intensity/strength can be expressed by formula

$$K_{н(i,j)} = \frac{t_{(L)\max} - t'_{кр(L)}}{t_{кр} - t'_{кр(L)}}.$$

For example let us take graph/curve (Fig. 44) and it is determined coefficients of intensity/strength of works $K_{н(5,9)}$ and $K_{н(10,13)}$.

First of all let us determine $t_{(L)\max}$ for works (5, 9) and (10, 13):

$$1)\ t_{(L)\max(5,9)} = t(0,1) + t(1,2) + t(2,3) + t(3,5) + t(5,9) + t(9,12) + t(12,14) = 5 + 5 + 5 + 15 + 15 + 30 + 0 = 75;$$

$$2)\ t_{(L)\max(10,13)} = t(0,1) + t(1,2) + t(2,3) + t(3,7) + t(7,10) + t(10,13) + t(13,14) = 5 + 5 + 5 + 5 + 0 + 30 + 15 = 65.$$

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We further determine durations of sections/segments $t'_{кр(L)}$ of critical path, which coincide with $t_{(L)\max(5,9)}$ and $t_{(L)\max(10,13)}$:

$$1)\ t'_{кр(L)(5,9)} = t(0,1) + t(1,2) + t(2,3) + t(3,5) = 5 + 5 + 5 + 15 = 30;$$

$$2)\ t'_{кр(L)(10,13)} = t_{(0,1)} + t_{(1,2)} + t_{(2,3)} = 5 + 5 + 5 = 15.$$

Having $t_{(L)\max}$ and $t'_{кр}$, we determine coefficients of intensity/strength for works (5, 9) and (10, 13):

$$1)\ K_{н\,(5,9)} = \frac{t_{(L)\max(5,9)} - t'_{кр\,(L)\,(5,9)}}{t_{кр} - t'_{кр\,(L)\,(5,9)}} = \frac{75-30}{170-30} = \frac{45}{140} = 0{,}32;$$

$$2)\ K_{н\,(10,13)} = \frac{t_{(L)\max(10,13)} - t'_{кр\,(L)\,(10,13)}}{t_{кр} - t'_{кр\,(L)\,(10,13)}} = \frac{65-15}{170-15} = \frac{50}{155} = 0{,}32$$

Absolute values of coefficient of intensity/strength of works are equal. Consequently, to both works it is necessary to pay identical attention. In works with the large $K_н$ the periods of execution harder, and to the work of this route/path it is necessary to pay larger attention.

Definition/determination of the coefficient of freedom.

In order to describe relative value of free reserve of operating time r_c, is determined coefficient of freedom $K_{c\,(i,j)}$ according to formula

$$K_{c\,(i,j)} = \frac{t_{р\,(j)} - t_{п\,(i)}}{t_{(i,j)}}.$$

This coefficient is shown, in how often it is possible to increase operating time, without affecting periods of accomplishment of all events and all remaining work of net/system.

If work has free reserve of time, then

$$K_{c\,(i,j)} > 1.$$

If $K_{c(i,j)} < 1$, then this indicates absence of free reserve of time in this work.

Definition/determination of the probability of the execution of terminal or any control event within estimated periods.

In determined nets/systems, in which are given single-valued estimations/evaluations of time of execution of works (on basis of experience/experiment/lesson, norms, regulations or manuals), probability of execution of any event is equal to one.

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In stochastic nets/systems (i.e. in nets/systems, temporary/time estimations/evaluations where they are entered/written on basis of three estimations/evaluations - a, m and b), in which there is large quantity of events and normal distribution performs, probability of accomplishment of event within estimated period can be determined from formula

$$P_{(i)} = \Phi\left(\frac{t_{3i} - t_{p(i)}}{\sqrt{\sum \sigma^2}}\right), \qquad (24)$$

where $P_{(i)}$ - probability of accomplishment of interesting us event;

Φ - Laplace function;

$t_{\text{эт}}$ - directive period;

$t_{p(j)}$ - time of early accomplishment of event J;

$\sum \sigma^2$ - sum of variances of works, which were utilized during calculation of earliest period of offensive of corresponding event ($t_{p(j)}$).

According to formula (24) it is possible to determine probability of accomplishment of any event in net/system. However, this probability is determined only for the important control events and for the terminal event in the net/system. After determining the probability of the accomplishment of the terminal event in the net/system, we establish/install the probability of the accomplishment of the planned/glide operation/process (process) thereby.

Definition/determination of probability of accomplishment of operation/process (process) within planned periods makes it possible to determine quality of planning process.

On the basis of common sense in military affairs will not be as

long as carried out special research, apparently, with estimation/evaluation of probability of end of process (event) it is possible to accept the same criteria, which are utilized in national economy, namely probability of accomplishment of terminal or any control event must be in limits

$$0,35 < P_{(i)} < 0,65. \qquad (25)$$

This inequality means that planned/glide process will be carried out in period and further optimization (improvement) of net/system, which is examined in following chapter, one ought not to do.

If probability of execution of operation/process (event) is less than 0.35, then this means that there is few chances to lie/fall/lay planned/glide process in estimated period. Inequality $P_{(i)} > 0.65$ will mean that in the net/system there are many unused reserves. In both cases it is necessary to optimize net/system and to attain the execution of inequality indicated above (25).

Network graphs can be calculated by hand (by method of manual algorithm), also, in digital electronic computers.

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In this work methods of calculation/crew of network graphs by

method of manual algorithm will be most in detail examined, since small nets/systems (before 200 events) can be calculated by hand almost for the same time, as on computer(s). This is explained by the fact that input of initial data, processing the obtained results and their bringing to the form, convenient for the analysis with the existing input units and display/representation of information, occupy much time. However, there is an experience/experiment/lesson of manual calculation/crew and more complicated nets/systems, which contain from one-and-a-half to two and one-half thousands of events.

Under conditions for combat operations manual calculation/crew of nets/systems in many instances will be necessary. Although as a whole it is necessary to keep in mind which, where they will be computer(s), is expedient during the calculation/crew of nets/systems to use these vehicles/computers.

Earlier has already been indicated that network graphs can be calculated by analytical, tabular and graphic methods. The analytical method, examined in S5, consists in the calculation/crew of the parameters of network graph according to the formulas. This method of calculation/crew is basis during the calculation/crew of graphs/curves by tabular and graphic methods. However, obtained by this method results need systematization, on what it is necessary to spend supplementary time.

Tabular and graphic calculation methods provide systematization of calculations/crews, which creates convenience in analysis of net/system. In §6 and 7 are examined these two calculation methods.

§6. Tabular calculation method.

Tabular calculation method consists in the fact that on basis of comprised graph/curve is filled design schedule, on which, utilizing special algorithm (sequence of actions), are calculated all parameters of network graphs. This is the most convenient method, which gives the capability to more fully calculate the basic parameters of network graph.

Table 8 shows tabular method of calculation of initial network graph, shown in Fig. 31. Table 8 shows all designed parameters of network graph.

Let us examine order of calculation of parameters of graph/curve according to table.

Definition/determination of early beginning and early termination of works.

In order to make calculation/crew of these parameters, they enter as follows.

1. Form of design schedule (Table 8) is prepared.

2. In graphs/counts 1 and 2 of Table 8 enter from network graph all works, entering net/system. Works are entered by the numbers of the events, which limit each work, for example (0, 1), (1, 2), (2, 3) and the like. In this case it is important so that the works would be entered in the strictly defined order/formation according to the degree of the increase of the initial numbers of works. For example, in table 8 recording is initiated from work (0, 1), then goes recording according to the increasing numbers of the initial events of the works: (1, 2), (2, 3), (3, 4) and so forth.

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It is necessary to keep in mind that if from one event emerge several works, then they all are written/recorded in table also in increasing order/formation, but only on final event. In graph/count 1 one and the same number is placed. For example, in the graph/curve (Fig. 31) from event (3) emerge four works. In graph/count 1 are

written/recorded four times (in four lines) the number of initial event, i.e., event (3), while in graph/count 2 the numbers of the final events of works on their increase are written, i.e., numerals 4, 5, 6, 7 are placed. Thus write/record all works, which come out from the third event, i.e., works (3, 4), (3, 5), (3, 6) and (3, 7).

Further they act analogously, until all work of net/system are inscribed.

3. Then in graphs/counts 4 and 7 against each work enter their duration in some ones measurements (minutes, hours, days or weeks). Since the duration of each operation is a concrete/specific/actual quantity/magnitude, in each line of both complexs, i.e., in graphs/counts 4 and 7 they will stand the same numerals for each work. For the calculation/crew is conveniently the operating time written in two graphs/counts: in graph/count 4 - for the definition/determination of the early termination of work, in graph/count 7 - for the definition/determination of the late beginning of work. These are is two complexs with the duration of one and the same operations.

4. After this according to Table 8 early beginning and early termination of works are determined, i.e., is conducted calculation/crew and filling of complexs 3 and 5. In this case are

recommended both complexs to fill simultaneously line-by-line, i.e., to at first fill line in graph/count 3, and then in graph/count 5 and only after this to convert/transfer to the following lower line. Lines in the graphs/counts are filled downward.

Order/formation of filling of complexs 3 and 5 is realized as follows:

- at first in first line of complex 3 is entered/written time of early beginning of work, which begins from initial (zero) event; initial event undertakes reference point; therefore beginning of first work (0, 1) are considered zero and it is written/recorded in first line of complex 3;

- then to early beginning of work (0, 1) is added duration of this operation and thus is obtained early termination of work (0, 1) and it is entered/written this time in first line of complex 5; in this case they use formula

$$t_{р.о(0,1)} = t_{р.н(0,1)} + t_{(0,1)} = 0 + 5 = 5.$$

Actually/really in first line of complex 5 stands numeral 5.

Further filling of table is based on that rule, that early termination of previous work is early beginning of subsequent work,

i.e., $t_{p.o\,ll.\,n} = t_{p.\,n\,ll.\,kv}$

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Table 8. Tabular method of calculation of graph/curve.

(1) Работы		(4) Раннее начало работы	(5) Продолжи-тельность работы	(6) Раннее окончание работы	(7) Позднее начало работы	(5) Продолжи-тельность работы	(8) Позднее окончание работы	(9) Полный резерв времени работы	(10) Частный резерв времени первого вида	(11) Частный резерв времени второго вида
(2) Начальное событие	(3) Конечное событие									
1	2	3	4	5	6	7	8	9	10	11
0	[illegible]	0	5	[illegible]	0	5	5	0	0	0
[illegible]	2	[illegible]	5	[illegible]	5	5	10	0	0	0
[illegible]	3	10	5	15	10	5	15	0	0	0
3	4	15	5	20	85	5	30	70	70	0
3	5	15	15	30	15	15	30	0	0	0
3	6	15	10	25	100	10	110	85	85	0
3	7	15	5	20	120	5	125	105	105	0
4	8	20	0	20	90	0	90	70	0	70
4	11	20	60	80	90	60	150	70	0	70
5	8	30	60	90	30	60	90	0	0	0
8	9	30	15	45	125	15	150	95	95	10
5	10	30	15	45	110	15	125	80	80	0
6	[illegible]	25	30	55	[illegible]	[illegible]	150	85	0	0
7	10	20	0	20	125	0	125	105	0	25
7	13	20	30	60	125	30	155	105	0	25
8	11	90	60	150	90	60	150	0	0	0
[illegible]	12	55	30	85	[illegible]	30	170	85	0	0
[illegible]	14	55	15	70	155	15	170	100	15	100
10	13	45	30	75	125	30	[illegible]	80	0	0
11	14	150	20	170	150	20	[illegible]	0	0	0
12	14	85	0	85	170	0	170	85	0	85
13	14	75	15	90	[illegible]	15	170	80	0	80

(12) Сравнивают и берут максимум

(13) Сравнивают и берут минимум

Key: (1). Work. (2). Initial event. (3). Final event. (4). Early beginning of work. (5). Operating time. (6). Early termination of work. (7). Late beginning of work. (8). Late termination of work. (9). Total/full/complete reserve of operating time. (10). Local reserve of time of first form. (11). Local reserve of time of second form. (12). They compare and they take maximum. (13). They compare and they take minimum.

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Therefore, in order to write the early beginning of work (1, 2), is taken the early termination of the previous work, i.e., work (0, 1), which is equal to 5 (first line of complex 5), and is entered/written this time into the second line of complex 3 against work (1, 2). This there will be the early beginning of the subsequent work with respect to work (0, 1).

Algorithm of activities during manual calculation/crew in this case is shown in table 8 by arrows/pointers with triangles in first, second and third lines on top.

If among previous works there are works, entering one event and, consequently, also which are finished to one number, then for early beginning of subsequent work is taken maximum value of early termination of works, entering one event, i.e., being finished by one and the same number. For example, in Table 8 are two works, which are finished by event (8), namely works (4, 8) and (5, 8), whose early terminations are respectively equal to 20 and 90 units of time. For earlier it began subsequent after them work (8, 11), which begins from the event, by which the preceding/previous works ended, it is

necessary to take maximum quantity/magnitude, i.e., the early termination of work (5, 8), equal to 90 units of time.

Algorithm of activities during manual calculation/crew in this case is shown in table 8 by arrows/pointers with circles in the eighth, tenth and sixteenth lines on top.

In this order/formation downward to end of table are determined early beginning and early termination of works.

Thus, after examining order/formation of definition/determination of early beginning and early termination of works, it is possible to generalize: for determination of time of early beginning of this work all works, entering initial event of this work, are examined. From the complex of the early termination of entering works $t_{р.о(h,i)}$ is driven out/selected the maximum time of the termination of works, which is transferred in the complex of the early beginning of this work $t_{р.н(i,j)}$. Calculation/crew is conducted downward; $t_{р.о(i,j)}$ - time of the early termination of work (i, j) is equal to the time of the early beginning of this work plus its duration, i.e., $t_{р.о(i,j)} = t_{р.н(i,j)} + t_{(i,j)}$.

Definition/determination of late beginning and late termination of works.

Late beginning $(t_{п.н(i,j)})$ and late termination $(t_{п.о(i,j)})$ of works are determined in reverse order/formation, from bottom to top. In this case graphs/counts 6 and 8 (Table 8) are filled so line-by-line simultaneously: at first is filled line in graph/count 8, and then the same line in graph/count 6. Calculation/crew begins from the definition/determination of the time of the late termination of the latter in design schedule of work. In Table 8 this will be work (13, 14).

Of previously material presented it is known that latter/last event of net/system always lies/rests on critical path.

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But the time of the early termination of the latter/last work, which lies on the critical path and being finished by the terminal critical event, is equal to the time of its late termination. Based on this in Table 8 it is found latter/last critical work, is taken the time of its early termination and it is placed this numeral in complex 8 in the same line, in which is registered this work. The same numeral is entered/written in graph/count 8 in the lines of all those works, which have by final event the terminal event of net/system. for

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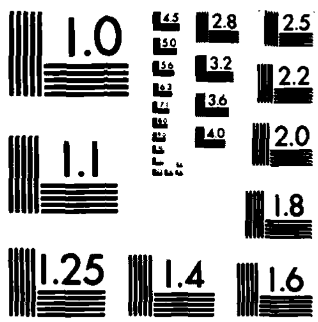

MICROCOPY RESOLUTION TEST CHART
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example, in Table 8 latter/last critical work, which is finished by terminal event (14), is work (11, 14). In graph/count 5 is located the time of the early termination of this work, which was already earlier calculated. This time is equal to 170 units of time. Obtained number 170 is placed in graph/count 8 against all works, which are finished by the terminal event of net/system, i.e., with event (14). Thus, number 170 is entered/written in graph/count 8 against works (9, 14), (12, 14) and (13, 14).

Then table is calculated, beginning from latter/last line from bottom to top. In this case the time of the late termination of works ($t_{n.o(i,j)}$), is taken the time of work itself (i, j) is deducted from it and difference is entered/written in graph/count 6 in the same line. In this case they use the formula

$$t_{n.n(i,j)}=t_{n.o(i,j)}-t_{(i,j)}.$$

In our estimated Table 8 work (13, 14) is latter/last work. In graph/count 8 the time of its late termination, equal to 170, is found, from which they deduct the operating time (13, 14), equal to 15 min, and the obtained difference 170-15=155 they enter/write in complex 6 in the line, on which is registered work (13, 14). Then, heaving along complex 2 from bottom to top, they follow the final events of works. If the final event, which stands in the upper line, the same as in the lower line (for example as in our example event

(14) in the first, second, third and fifth lines from below), operation/process is repeated. In this case in the second line of complex 2 we from below find final event (14), i.e., the same as in the lower line. The time of the late termination of all works, which are finished by event (14), is already determined. Therefore of 170 is deducted $t_{(12,14)}$ which is equal to zero, and 170 are placed in the second line from below complex 6, etc.

If numeral in upper line of complex 2 does not coincide with numeral of lower line of the same complex, then they enter as follows: they memorize obtained numeral and is found the same numeral, but in graph/count 1 it is below. After finding necessary numeral in graph/count 1, in the line, in which proved to be the obtained numeral, they follow to the right to complex 6 and memorize the number, which stands in this complex. Then this number they transfer in complex 8 and place in the line, on which was found the numeral in graph/count 2, different from the numeral, which is located on the preceding/previous line.

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Algorithm of this rule is shown in Table 8 by arrows/pointers with squares.

We so entered: they found the late beginning of work (13, 14), which is equal to 155 min, and they placed it as the late termination of this work (10, 13).

In such a case, when in graph/count 1 there are several identical numerals, and this means that from one event several works emerge, then minimum value of late beginning of all works, which begin from one and the same numeral, is taken and they enter then, as this was in first case. For example, it is necessary to determine the late termination of work (6, 9). Final event of this work - event (9). After memorizing it, they turn to complex 1 and note there two numerals 9, from which begin works (9, 12) and (9, 14). Is found the late beginning of these works $t_{n.\,n\,(9,\,12)}==140$ and $t_{n.\,n\,(9,\,14)}=155$, they take minimum value, i.e., $t_{n.\,n\,(9,\,12)}==140$ and is set itself this numeral as the late termination of work (6, 9). Since in our example there is one work, which is finished by event (9) [this work (5, 9)], then to this work is set itself the time of late termination $t_{n.\,o\,(5,\,9)}=140$.

Algorithm of activities in this case is shown in table 8 by arrows/pointers with rectangles.

For example, following according to table from bottom to top, they determine $t_{\text{п.о}}$ works (13, 14), (12, 14), (11, 14) approach work (10, 13), whose final event (13) differs from final event of work, written by line below, i.e., work (11, 14). After memorizing number 13, is focused attention on the numerals, which stand more left in graph/count 1 and it is lower than this work. Actually/really in graph/count 1 on the latter/last line there will be number 13 - this initial event of work (13, 14). Following in this line to the right to complex 6, in which is found number 155, they memorize this number and they transfer it in complex 8 to the line, in which work (10, 13) is registered, i.e., where stands number 13, from which was initiated the search.

If we analyze these activities, then they consists of following. It was necessary to find the late termination of work (10, 13). If this is expressed in the diagram, then it will appear, as shown in Fig. 50.

In Fig. 50 it is evident that work (10, 13) is this work, and work (13, 14) of following. Event (13) is the boundary event between these works. Work (10, 13) concludes with event (13) and another work (13, 14) begins with the same event (13). It means, as soon as work (10, 13) ends, work (13, 14) immediately begins, i.e., the late beginning of work (13, 14) is the late termination of work (10, 13).

Fig. 50. Diagram/plan/circuit of the dependence of works.

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In this order/formation calculation/crew to end (to top of table) is conducted.

Thus, after examining order/formation of definition/determination of late termination and late beginning of works, it is possible to draw conclusions:

- for determination of time of late termination of this work are examined all works, which come out from final event of this work; from complex of 6 late beginnings of coming-out works ($t_{п.н\,(j,k)}$) it is driven out/selected minimum time of late beginning, which is transferred in complex of 8 late terminations of this work ($t_{п.о\,(i,j)}$); calculation/crew it is conducted from bottom to top;

- time of late beginning of this work is equal to time of late termination of this work minus its duration, i.e.

$$t_{п.н\,(i,j)} = t_{п.о\,(i,j)} - t_{(i,j)}.$$

Definition/determination of the total/full/complete and local reserves of operating time.

Total/full/complete reserve of operating time is located as difference between time of late termination of work ($t_{п.о(i,j)}$) and time of early termination of work ($t_{р.о(i,j)}$) or as time difference of late beginning of work ($t_{п.н(i,j)}$) and early beginning of work ($t_{р.н(i,j)}$), т. е.

$t_{п.о(i,j)} - t_{р.о(i,j)}$ or $t_{п.н(i,j)} - t_{р.н(i,j)}$.

According to table this reserve is defined as difference in data, placed in graphs/counts 8 and 5 or graphs/counts 6 and 3. For example, let us determine the reserve for work (3, 6). For this we take work (3, 6) and against it in graph/count 8 find numeral 110. From it it is subtracted numeral, which is located in graph/count 5 against the same work. This is numeral 25. The difference between the data graph/count 8 and 5 of this work, equal to 85, we place in complex 9 against this work.

For determination of local reserve of time of first form ($P'_п$) works, which have identical initial events, are examined. From complex 6 of these works is driven out/selected minimum time $t_{п.н}$, which is deducted from time $t_{п.н}$ of this work. If from event only one

work emerges, then the local reserve of first type P'_n of this work is equal to zero, for example in table 8 $P'_{n(1,2)} = 0$.

According to tables 8 let us determine local reserve of first form of work (3, 4). In graph/count 1 the works are found. beginning from event (3). Such works four (3, 4; 3, 5; 3, 6; 3, 7). In graph/count 6 the minimum value of these works is found. Such value in work (3, 5), which is equal to 15 min. Then from $t_{n.n}$ each of these four works, which begin from event (3), deduct the obtained minimum value of work (3, 5), i.e., 15 min.

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Difference is placed in complex 10 respectively against each work. They calculate the local reserve of the first form for the works:

$$P'_{n(3,4)} = t_{n.n(3,4)} - t_{n.n(3,5)} = 85 - 15 = 70;$$
$$P'_{n(3,5)} = t_{n.n(3,5)} - t_{n.n(3,5)} = 15 - 15 = 0;$$
$$P'_{n(3,6)} = t_{n.n(3,6)} - t_{n.n(3,5)} = 100 - 15 = 85;$$
$$P'_{n(3,7)} = t_{n.n(3,7)} - t_{n.n(3,5)} = 120 - 15 = 105.$$

Actually/really in Table 8 in graph/count 10 against these works obtained numerals stand.

For definition/determination of local reserve of second type

$P'_{n(i,j)}$ of this work works, which have identical final events, are examined. From complex 5 of these works is driven out/selected the maximum time of the termination of work, from which is deducted $t_{p.o}$ this work.

If into event only one work enters, then local reserve of second type P'_n of this work is equal to zero. According to tables 8 let us determine the local reserve of the second form of work (5, 9). In graph/count 2 the works, which have identical events, are found. Such works two: (5, 9) and (6, 9). They turn to complex 5, where is calculated $t_{p.o}$ these works. In work (5, 9) $t_{p.o(5,9)} = 45$, while in work (6, 9) $t_{p.o(6,9)} = 55$ Is taken maximum quantity/magnitude 55. From this quantity/magnitude deduct $t_{p.o}$ each work.

Consequently, $P'_{n(5,9)} = 55 - 45 = 10$; $P'_{n(6,9)} = 55 - 55 = 0$.

Actually/really, if we turn to Table 8, then in graph/count 11 let us see numeral 10 against work (5, 9), and against work (6, 9) - numeral 0.

In work (3, 6) into final event enters only one work, therefore, $P'_{n(3,6)} = 0$.

S7. Graphic calculation method.

Graph method is applied, as a rule, during calculation/crew of small nets/systems. The fact that all estimated parameters are determined directly on the graph/curve, is its special feature/peculiarity.

There are two varieties of graph method of calculation/crew: 1) calculation/crew with recording of estimated parameters and with change in graphic trace of net/system even 2) calculation/crew with recording of estimated parameters without redrawing of net/system.

Latter/last method of calculation/crew in turn is subdivided in multisector and in four-sector.

In military affairs four-sector graph method of calculation/crew is most acceptable, since it is more compact and convenient for rapid calculation/crew of small nets/systems.

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This exactly is valuable during the use of network methods in the conditions of the rapidly changing situation in the course of combat operations. With this method the small circle of net/system, which

designates event, is divided into four parts (sector/arc). Fig. 51 shows the conventional designations, accepted with the four-sector method of the calculation/crew of net/system.

Thus, on the basis of Fig. 51, it is possible to conclude following: in upper sector/arc number of event is placed; in left sector/arc - is most earlier of possible periods time of beginning of work, which comes out of this event; in right sector/arc - most later permissible time of beginning of work, which comes out from this event; in lower sector/arc - reserve of time of this event.

Above arrows/pointers of numeral they indicate: numeral, which stands in the beginning of arrow/pointer, operating time; composed fraction at the end of arrow/pointer - reserves of operating time, where integer - total/full/complete reserve for work, numerator of fraction - local reserve of first form, denominator of fraction - local reserve of second type of this work.

Let us examine order of calculation of net/system by graph method. For this let us take our initial net/system - training tank battalion for the offensive from the position/situation of direct contact with the enemy (Fig. 31). The designed by graph method initial network graph is shown in Fig. 52.

Order of calculation of net/system is described below.

Calculation/crew of the earliest possible is temporary/time the beginning of works.

Most early possible time of beginning of works is calculated in order/formation from left to right, beginning from initial event and ending with that completing.

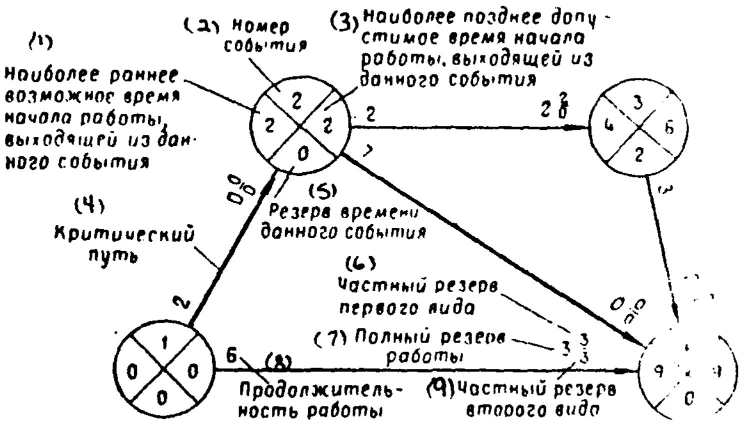

Fig. 51. The conventional designations accepted with the four-sector method of the calculation/crew of net/system.

Key: (1). Most early possible time of the beginning of the work of that coming out from this event. (2). Number of event. (3). Most later permissible time of beginning of work, which comes out from this event. (4). Critical path. (5). Reserve of time of this event. (6). Local reserve of first form. (7). Total/full/complete reserve for work. (8). Operating time. (9). Local reserve of second form.

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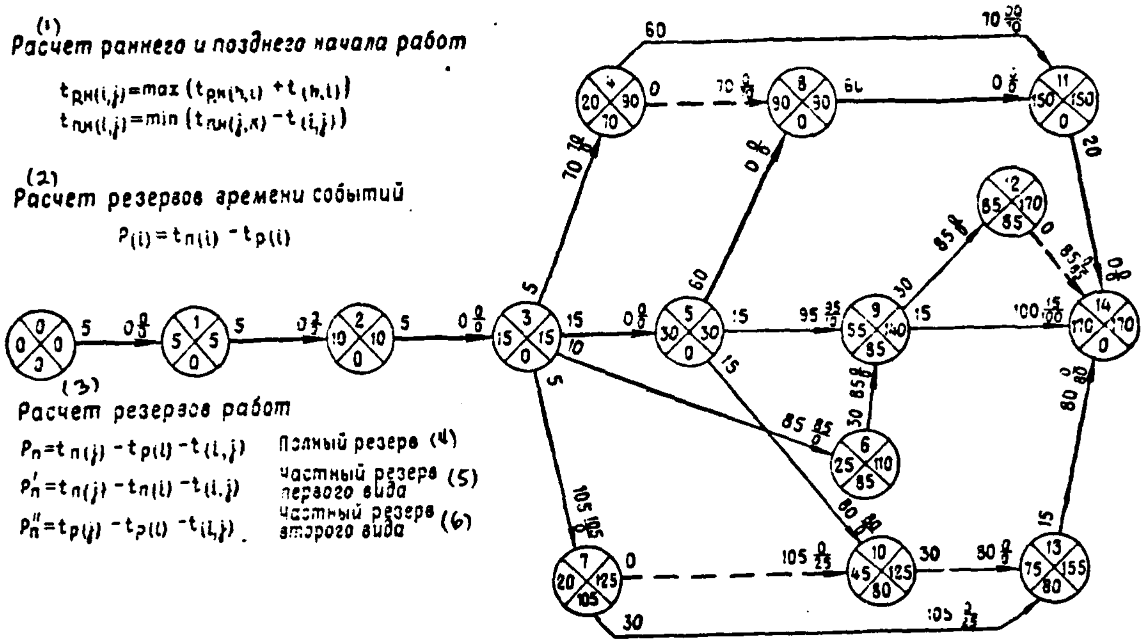

Fig. 52. Graphic calculation/crew of initial network graph.

Key: (1). Calculation/crew of the early and late beginning of works. (2). Calculation/crew of reserves of time of events. (3). Calculation/crew of reserves for works. (4). Total/full/complete reserve. (5). Local reserve of first form. (6). Local reserve of second form.

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Moreover for the earliest beginning of work the greatest value of the

accumulated time along all routes/paths, which lead to this event, is accepted. Calculation/crew is conducted according to the algorithm (formula 10') in the following order/formation.

For initial event and, consequently, also for works, which come out from initial event, it earlier began equally to zero.

Thus, let us formulate written in mentioned formula (10') algorithm by words: early beginning of this work (i, j) is equal to maximum value of sum of early beginning and duration of operations, which precede this work.

If only one work precedes this work, then its earlier beginning is equal to sum of early beginning and very duration of previous operation. For example, let us determine the early beginning of works (1, 2) and (2, 3):

$$t_{\text{р. н}(1,2)} = t_{\text{р. н}(0,1)} + t_{(0,1)} = 0 + 5 = 5;$$
$$t_{\text{р. н}(2,3)} = t_{\text{р. н}(1,2)} + t_{(1,2)} = 5 + 5 = 10.$$

During definition/determination of early beginning of work (1, 2) according to graph/curve they perform as follows: is found event (0) and they take in its left sector/arc time of beginning of work (0, 1), which is equal to zero, and is added to it time of work itself (0, 1), equal to 5 min. The obtained sum is placed in the left sector/arc of event (1). Numeral 5, written into the left sector/arc

of event (1), shows the early time of the beginning of work (1, 2).

For definition/determination $t_{p.н(2,3)}$ is found event (2), they take in its left sector/arc time of beginning of work (2, 3), equal to 10, and is added to it time of work itself, equal to 5 min. They enter/write the obtained sum into the left sector/arc of event (3). This time will be the early time of the beginning of all works, which come out from event (3), i.e., works (3, 4) (3, 5) (3, 6) (3, 7).

If several works precede this work, then early beginning of this work is determined on maximum sum of time of beginning and duration of all previous works. For example, in our example during the definition/determination of the early beginning of work (8, 11) we examine two previous works, namely (4, 8) and (5, 8). Let us determine $t_{p.н(8,11)}$ from these entering works:

$$t_{p.н(8,11)} = t_{p.н(4,8)} + t_{(4,8)} = 20 + 0 = 20;$$
$$t''_{p.н(8,11)} = t_{p.н(5,8)} + t_{(5,8)} = 30 + 60 = 90.$$

Bierut maximum sum, i.e., $t_{p.н(8,11)} = 90$ is placed it in left sector/arc of event (8). This is the early beginning of work (8, 11).

According to such rules early beginning of all works is determined and they reach other terminal event in net/system.

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Calculation/crew of the latest permissible time of the beginning of works.

Most late time of beginning of work is calculated in reverse order/formation, than during definition/determination of time of early beginning of work, and it is conducted by back stroke from right to left, beginning from terminal event and ending with initial.

For terminal event in net/system early beginning of subsequent works, which this event, as is known, does not have, indicates at the same time late termination of all previous works. Therefore the early beginning of work from the left sector/arc of the terminal event is transferred into the right sector/arc of this event and calculation/crew in the reverse order/formation (from right to left) before the initial event begins. Moreover in the right sector/arc the minimum values of the difference between the late beginning of the subsequent work and the duration of this operation are written/recorded.

Calculation/crew is conducted on algorithm (formula 12).

Let us calculate according to our graph/curve late beginning of

works (11, 14) (8, 11) and (5, 8):

$$t_{\text{п. н}(11,14)} = t_{\text{п. н}(14,k)} - t_{(11,14)} = 170 - 20 = 150;$$
$$t_{\text{п. н}(8,11)} = (t_{\text{п. н}(11,14)} - t_{(8,11)}) = 150 - 60 = 90.$$

During definition/determination according to graph/curve we enter as follows: from numeral 170, which stands in right sector/arc of event (14), it is subtracted duration of operation (11, 14), equal to 20, we obtain 150. The obtained numeral it is brought in into the right sector/arc of event (11). Analogously we act also during definition/determination $t_{\text{п. н}(8,11)}$: 150 it is subtracted by 60 and we write/record into the right sector/arc of event (8) the result, equal to 90.

If from event emerge several works as, for example, of event (5), then they enter as follows: they calculate late beginning of all works, which come out from this event, and is taken minimum value of obtained times.

In our example:

$$t_{\text{п. н}(5,8)} = t_{\text{п. н}(8,11)} - t_{(5,8)} = 90 - 60 = 30;$$
$$t_{\text{п. н}(5,9)} = t_{\text{п. н}(9,12)} - t_{(5,9)} = 140 - 15 = 125;$$
$$t_{\text{п. н}(5,10)} = t_{\text{п. н}(10,13)} - t_{(5,10)} = 125 - 15 = 110.$$

Number 36 is smallest value from these three quantities/magnitudes. Therefore number 30 is set itself in the right sector/arc of event (5). We recall that the minimum time under these

conditions is taken in order to ensure the necessary time for the accomplishment of long runnings and not to influence the designed period of the termination of operation/process (process) as a whole. By this order/formation during the calculation/crew they reach before the initial event.

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Calculation/crew of the reserves of time.

Reserve of time of each event is defined as difference between late and early time of accomplishment of each event:

$$P_{(i)} = t_{n\,(i)} - t_{p\,(i)}$$

During definition/determination according to graph/curve they enter as follows: from quantity/magnitude of right sector/arc of event they deduct quantity/magnitude of left sector/arc of the same event. They will bring in result into the lower sector/arc of event. For example, let us calculate the reserve of time for events (3) (4) and (8):

$$P_{(3)} = t_{n\,(3)} - t_{p(3)} = 15 - 15 = 0;$$
$$P_{(4)} = t_{n(4)} - t_{p\,(4)} = 90 - 20 = 70;$$
$$P_{(8)} = t_{n\,(8)} - t_{p(8)} = 90 - 90 = 0.$$

Total/full/complete reserve temporary service (P_n) it is

calculated as difference between late time of accomplishment of event, by which is finished work, with early time of accomplishment of event, from which begins this work, and with time (duration) of work itself:

$$P_{n}=t_{n(j)}-t_{p(i)}-t_{(i,j)}$$

For example, total/full/complete reserve for work (9, 14) is equal to

$$P_{n(9,14)}=t_{n(14)}-t_{p(9)}-t_{(9,14)}=170-55-15=100.$$

Obtained quantity/magnitude is set itself at the end of arrow/pointer as integer of fraction, which shows reserves of time.

Determining general reserve for work according to graph/curve, they enter as follows: from quantity/magnitude of right sector/arc of event (14) they deduct quantity/magnitude of left sector/arc of event (9) and duration of operation itself:

$$P_{n(9,14)}=170-55-15=100.$$

Local reserve of first form ($P'_{n(i,j)}$) is calculated as follows:

$$P'_{n(i,j)}=t_{n(j)}-t_{n(i)}-t_{(i,j)}.$$

For work (9, 14) it is equal to

$$P'_{n(9,14)}=t_{n(14)}-t_{n(9)}-t_{(9,14)}=170-140-15=15.$$

According to graph/curve this reserve is determined as follows: from contained right sector/arc of event (14) is deducted quantity/magnitude of right sector/arc of event (9) and duration of operation (9, 14):

$$P'_{n(9,14)} = 170 - 140 - 15 = 15.$$

Obtained result is placed as numerator of fraction, entered/written above at the end of work (9, 14).

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Local reserve of second form ($P''_{n(i,j)}$) is defined as difference

$$P''_{n(i,j)} = t_{p(j)} - t_{p(i)} - t_{(i,j)}.$$

For work (9, 14) it is equal to

$$P''_{n(9,14)} = t_{p(14)} - t_{p(9)} - t_{(9,14)} = 170 - 55 - 15 = 100.$$

According to graph/curve this reserve is determined as follows: from quantity/magnitude of left sector/arc of event (14) is deducted quantity/magnitude of left sector/arc of event (9) and duration of operation (9, 14):

$$P''_{n(9,14)} = 170 - 55 - 15 = 100.$$

We write/record obtained number as denominator of fraction, entered/written on top at the end of work (9, 14). Reserves for all works analogously are determined.

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Chapter III.

OPTIMIZATION OF NETWORK GRAPHS AND THEIR USE IN THE COURSE OF THE EXECUTION OF PLAN (DEVELOPMENT).

1. Methods of optimization of nets/systems.

Duration of critical path, obtained as a result of analysis of initial network graph (Fig. 31), is equal to 170 min, i.e., 2 h and 50 min. However, according to the conditions, accepted by us, battalion commander must finish all works, connected with training of battalion for the offensive, for 2 h 10 min. Consequently, the outlined original plan of work must be shortened for 40 min.

How to attain shortening original plan of training battalion for offensive for 40 min? Within the framework of traditional methods the plannings in such cases were usually limited either to the volitional activities, based on the intuition or to the recoil of instructions subordinated in the form: "must be carried out in time".

With execution of simple works (processes) of intuition, based on experience/experiment/lesson, it can prove to be already sufficiently. However, with the execution of complicated processes it is necessary not intuition, but precise calculations/crews. The network method of the planning and management exactly is that instrument, which makes it possible to calculate, is it possible the planned/glide process under the given specific conditions to shorten to the required quantity of time and thus to lie/fall/lay in the directive periods.

For analysis of complicated processes (developments) network model is simply necessary, since it gives capability to discard unfavorable versions of planning process and it makes it possible to see, due to what it is possible to accelerate it.

What recommendations can give to us network model?

First of all it will prompt, which to strive shortening periods of accomplishment of process is necessary due to shortening of critical path, but not due to shortening of all routes/paths.

If after first shortening it seems that new critical path,

although it is shorter than preceding/previous, exceeds directive periods, then it is necessary to shorten it. And so they act until they lie/fall/lay in the appointed as senior commander time. This process is called the optimization (improvement) of net/system.

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Optimization of net/system, as it was already noted, can be carried out through different criteria: to time, resources/service lives, costs/values, to flow.

S8. Optimization of net/system on the time.

Through criterion of time it is expedient to carry out optimization of graph/curve through following paths.

1. To verify correctness of entry of temporary/time estimations/evaluations of works of critical zone. In the case of their unjustified overestimate to bring into accord with the steady norms of the execution of works. One should approach the minimally permissible duration of the operations of critical zones. But if temporary/time estimations/evaluations are not overstated, then cannot be reexamined them arbitrarily for the purpose of obtaining the planned period of the completion of the plan/layout of process

(development).

2. To analyze capability of intensification of execution of critical works due to use of resources/service lives of works of noncritical zone, which are arranged/located reserves of time. However, it is necessary to use reserves in the reasonable limits. The tendency to decrease the reserves in order in this way to shorten general/common/total life, can lead to an increase of the number of critical paths and finally to the attempt to redistribute resources/service lives so that all routes/paths will become critical. But this will hinder/hamper the control of process in the course of the execution of works, since will not be sufficient reserves for eliminating the possible disruptions/separations.

3. To analyze capability of maximum coincidence of critical works by development of works and parallel and execution. Let us note that the coincidence of critical works in the time gives the greatest effect.

4. To change technology (sequence/consistency) of execution of works for the purpose of shortening general/common/total duration, i.e., to change topology of net/system. This route/path is most difficult and it it is desirable to apply when other receptions/methods do not lead to the desired results.

5. To shorten lives due to enlistment of supplementary resources/service lives.

In our example for shortening of time of training tank battalion for offensive we utilize third path.

Experience/experiment/lesson shows that shortening critical path must be begun from prolonged processes. Usually, other conditions being equal, the probability of their shortening is more, therefore, is more the expected effect. Here on the critical path (Fig. 31) of such processes three - this of work (5, 8) (8, 11) and (11, 14). It is obvious that their general/common/total duration can be abbreviated/reduced due to the development of works (5, 8) (8, 11) and their parallel execution, and also due to the simultaneous execution of work (11, 14) with work (8, 11).

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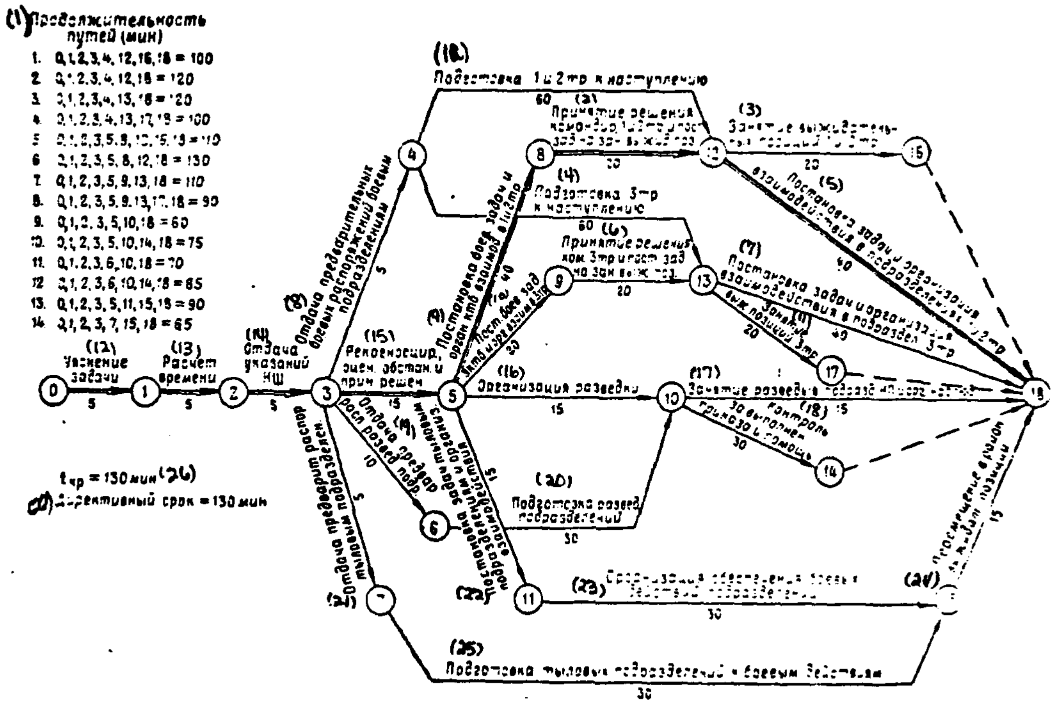

Fig. 53. Optimized initial network graph of training tank battalion for offensive from position/situation of direct contact with the enemy.

Key: (1). Duration of routes/paths (min). (1a). Preparation of 1 and 2 tr to offensive. (2). Acceptance of command decision 1 and 2 tr and

formulation of problem on occupying of expectant pos. (3). Taking of expectant positions 1 and 2 tr. (4). Preparation/training of 3 tr for offensive. (5). Formulation of problems and organization of cooperation in subunits 1 and 2 tr. (6). Acceptance of command decision of 3 tr and formulation of problem on taking of expectant pos. (7). Formulation of problems and organization of cooperation into subsection. 3 tr. (8). Issue of preliminary operation instructions to combat subunits. (9). Formulation/assignment of combat problems and organization of of ktb coop. in 1 and 2 tr. (10). Formulation of combat problem of 3 ktb and org of coop. in 3 tr. (11). Taking of expectant positions 3 tr. (12). Understanding problem. (13). Timing. (14). Issue of instructions NSh. (15). Recon., evaluation of situation and making decision. (16). Organization of reconnaissance/intelligence. (17). Exercise of recon. subdiv. NP and organization of observations. (18). Control of execution of order and aid. (19). Issue of preliminary instructions to recon. subdiv. (20). Preparation of recon. subunits. (21). Issue of preliminary instructions to rear subdiv. (22). Formulation of problems to rear subunits and organization of cooperation. (23). Organization of support/security/provision of combat operations of subunits. (24). Displacement into area of expectant positions. (25). Preparation of rear subunits for combat operations. (26). min. (27). Directive period =130 min.

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Let formulation of problems and organization of cooperation in 1st and 2nd tank companies be to perform battalion commander, and the same work in 3rd tank company - his deputy. Then on the new optimized graph/curve (Fig. 53) work (5, 8) is depicted as two works, namely works (5, 8) and (5, 9). Their duration will be respectively equal to 40 and 20 min.

So that work (11, 14) would be made simultaneously with work (8, 11) (Fig. 31), necessary that work (8, 11) would be partially carried out, i.e., so that company commanders would pose problems on advancement to their subunits. Under these conditions the tanks can occupy expectant positions during the formulation/assignment of problems and organizing the cooperation by company commanders. Optimized graph/curve (Fig. 53) this so shows: work (8, 12) (12, 16) and (12, 18).

On optimized graph/curve shortening critical path is achieved due to development of critical works and their parallel execution. As far as the temporary/time estimations/evaluations of works are concerned, they remained constant, for example, if on the initial graph/curve on work (5, 8) was spent 60 min (from the calculation/crew 20 min to each company), then on the optimized

graph/curve in works (5, 8) and (5, 9) on each company is spent also 20 min.

This development of works and their parallel execution made it possible to shorten critical path 40 min and to lie/fall/lay thus in directive period. Since the target is achieved, further optimization of graph/curve ceases.

Let us examine one additional example for optimization of net/system on time, but now already of region of planning combat training. There is no doubt about the fact that the general/common/total plan/layout of combat training will consist of a large number of events. However, for understanding of the essence of the process of the optimization of net/system it suffices to examine some unit of the general/common/total plan/layout.

Let some particular network graph, which reflects planning combat training of subunit in training center (Fig. 54), be given. The duration of critical path, as can be seen from graph/curve, it is equal to 18 training days. It is necessary to optimize the graph/curve indicated so that the period of the execution of the planned themes and exercises of curriculum would not exceed 12 training days.

During scheduling it was considered that for final adjustment of exercises of firings and driving it is necessary to emit daily three tanks.

Problem - of shortening duration of operations, which lie on critical path, on the whole on six days.

At first let us attempt to make this due to enlistment of supplementary resources/service lives.

In fact, works (1, 2) and (2, 6) can be accelerated, if to checking readiness of subunits for execution of firings by authorized shell and for firing itself to emit not on three tanks, but on six tanks..

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In this case the duration of operations (1, 2) and (2, 6) will be shortened doubly. Thus, due to the supplementary enlistment of technology it is possible to attain shortening the periods of the works indicated on six days. It would seem, problem was solved, they lay/fell/laid in the period indicated. But this is not so. It is necessary to remember that with the review of the periods of occurrence of an event can arise the new critical path, which now

will determine the time of the termination of all works.

In our example route/path, which passes through events (1), (2), (4), (6), (7) and (8), became this new critical path. Its duration, as it is not difficult to determine from that stated above, is equal to 13 days. This means that we should shorten the duration of new critical path the minimum to 24 hrs. Let us attempt to achieve this due to the parallel execution of works (1, 2) and (2, 4).

In our example partial execution of work (1, 2) will be sufficient condition for beginning of work (2, 4). After checking at least of one company for the purpose of the definition/determination of its readiness for the execution of firings by authorized shell it is possible it will be conduct exercises through fire control with the officers and the tank commanders of this company. This gives the capability to accurately define the parameters of this condition, to break work (1, 2) into two independent works and to change graph/curve in the manner that it is shown in Fig. 55.

Work (1, 2) in new, already optimized graph/curve is represented in the form of two works: $(1, 2_1)$ by duration during one day and $(2_1, 2)$ with duration during two days. The execution of work $(1, 2_1)$ is a sufficient condition for the beginning of work $(2_1, 4)$.

One should remember that each time after change in duration of critical path it is necessary to again make calculations/crews of all parameters of time according to changed graph/curve.

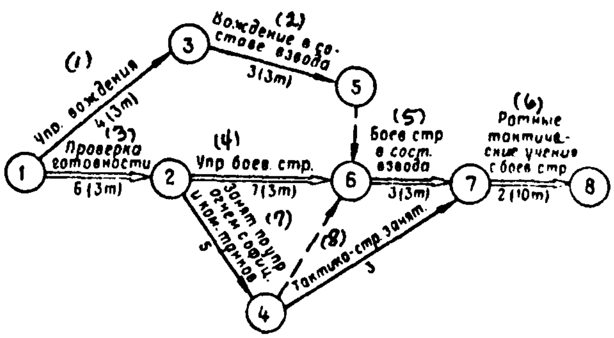

Fig. 54. Network model of the organization of the combat training of subunit in the training center.

Key: (1). Cont. of driving 4 (3 t). (2). Driving in personnel/staff/composition of platoon 3 (3 t). (3). Checking readiness 6 (3 t). (4). Cont. of combat firing 7 (3 t). (5). Combat firing in composition of platoon. (6). Military tactical exercises from combat firing 2 (10 t). (7). Occupied on cont of fire with off. and comm. tanks. (8). Tactics-firing is occupied.

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Producing miscounting net/system, we are convinced, what route/path, which passes in the initial graph/curve (Fig. 54) through events (1) (2) (4) (7) and (8) and which had the duration of 16 days, was shortened by 5 days and in the optimized graph/curve (Fig. 55) has the duration of 11 days, i.e., it does not exceed the duration of

critical path in the optimized graph/curve.

Thus, without changing duration of each operation individually, as a result of parallel execution of works we attained shortening time of entire process of training battalion on 6 training days.

It is obvious that new critical path must be subjected to further analysis. This process must be continued we will not as long as achieve the desired result, i.e., thus far the time of the execution of entire complex of works will be equal to the established/installed period or less it.

Capability is not excluded that in course of this consecutive shortening can be formed two critical paths and more. Our example illustrates this position/situation. In the graph/curve in Fig. 55 two critical paths are formed: one of them composes the sequence/consistency of works (1, 2_1), (2_1, 2), (2, 6), (6, 7), (7, 8), another - sequence/consistency of works (1, 3), (3, 5), (5, 6), (6, 7), (7, 8). On the duration each of them is equal to 12 days. If this version of graph/curve is not optimum, then to analysis must be subjected both these routes/paths, moreover first of all those works, which are general/common/total both for one and for another route/path. In our example this of work (6, 7) and (7, 8).

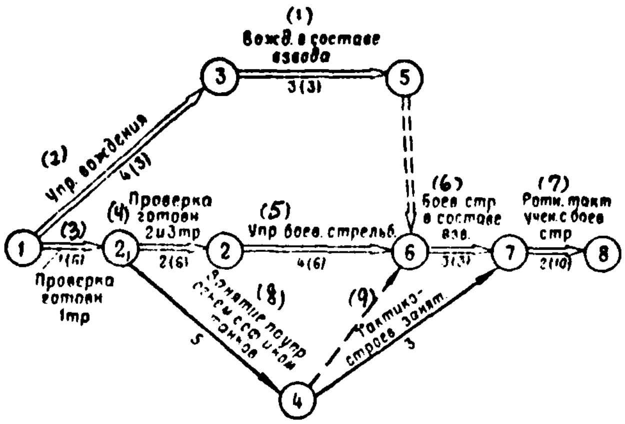

Fig. 55. Optimized on the time network graph of the organization of the combat training of subunit in the training center.

Key: (1). Leading in the personnel/staff/composition of platoon. (2). Cont. of leading. (3). Checking of readiness 1 tr. (4). Checking of readiness 2 and 3 tr. (5). Cont. of combat firings. (6). Combat firing in personnel/staff/composition of platoon. (7). Company tactics training with combat firing. (8). Exercise on cont. of fire with officers and comm. of tanks. (9). Tactical-firing employment.

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In this case to continue shortening critical path there is no need, since newly constructed and counted network graph (Fig. 55) provides length of critical paths (1, 2_1, 2, 6, 7, 8 and 1, 3, 5, 6,

7, 8), equal to 12 training days, which corresponds to established/installed directive period.

Improvement of network graph concludes when capabilities of shortening critical path are contained by.

In this connection-one should indicate one more advantage of use/application of methods SPU in comparison with existing methods of planning.

It is no secret that sometimes date of completion of works they assign, without having thought about capabilities and specific conditions for fulfillment of plan. In our example directive period they possibly restricted by 12 days because it was required to more rapidly free firing range and tankodrome in the training center. Network model and in this case will prove to be highly useful. If mission is not attained, it will comprehensively show the reasons for this. Furthermore, with the aid of the network model has the capability to determine the smallest periods, within which can be completed the planned/glide process.

We examined order/formation of optimization of net/system on time only based on two examples. But the field of application of network models is not completely limited to this. The procedure of

the optimization of net/system examined on the time it is very useful to utilize during the definition/determination of the ways of shortening the periods of the execution of different problems, solved by the troops/forces, in number of which they can be: the incline of the troops/forces on battle alarm/alert, the completion of march, assault crossing water obstacles, armament of crossings, conducting decontamination, engineering armament of defense area, exercise of defense, preparation/training and air landing operation, preparation/training and conducting tactical exercises, building of training and supply base, preparation/training and conducting competitions, sport holidays, preparation/training and conducting the marching drill reviews. It is shorter, in all processes, where it is necessary to economize time, network model will prove to be true/reliable/certain instrument for making/working out/producing of the optimum versions of activities.

Finally, utilizing methods of optimization, it is possible not only to forecast planned/glide processes, but also to inspect/check effectiveness and correctness of already carried out operations/processes and developments and to impartially reveal/detect those deficiencies/lacks and omissions, which occurred in these processes. This will help to avoid analogous countings/reckonings/errors in the future. This can prove to be highly useful during the preparation of the selections/analyses of

all possible exercises. Network model will help accurately to determine, through whose fault and what subunits were late with the accomplishment of objective, to what questions should be paid the attention for eliminating the revealed in the exercises omissions.

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Correct use of methods of optimization of network graph on time will allow commanders and staff officers to soundly find ways of shortening periods of execution of any complicated processes.

However, capabilities of method of network planning are by no means limited to this. In practice we frequently meet with the situation, when the expenditures of forces and resources, in other words material capabilities, prove to be decisive/key with the execution of the complex of works. In these cases the need for the optimization of net/system on the resources/service lives appears.

S9. Optimization of net/system on the resources/service lives.

Success of accomplishment of objective depends not only on clear organization of works, but also on that, how successfully distributed forces and resource, how correctly material resources are distributed. With the planning of work important value has

reaching/achievement of the economical expenditure of forces and resources, training time, etc. This is provided by a precise accounting of data, characterizing the sizes/dimensions material, human and money expenditures and their rational distribution. The methods of network planning make it possible to achieve the correspondence between the established/installed periods of the execution of works and the resources/service lives tempered for them.

Need for optimization of net/system on resources/service lives can arise during decision/solution of wide circle of problems, and in particular such, as:

- distribution of forces and resources with execution of combat tasks/missions;

- building of defensive installations, armament of crossings through water obstacles;

- material and technical support of combat operations of troops/forces;

- planning combat training;

- creation of units of training and supply base, etc.

Let us examine order/formation of optimization of network graph on temporary/time resources/service lives based on specific example.

Let there be particular network graph of combat training of subunit (Fig. 56). It is necessary to improve this network graph so that the training week would have a duration of 30 h. On the graph/curve of the numerals, which stand above the arrows/pointers and included in the brackets, indicate the total volume of theme in the hours, and the numerals, which stand under the arrows/pointers, a quantity of weeks, during which must be studied (they are developed) themes.

Optimize graph/curve we will be on spaces.

First space. Initial graph/curve is calculated. In our example the calculation/crew is conducted by graphic method (Fig. 57).

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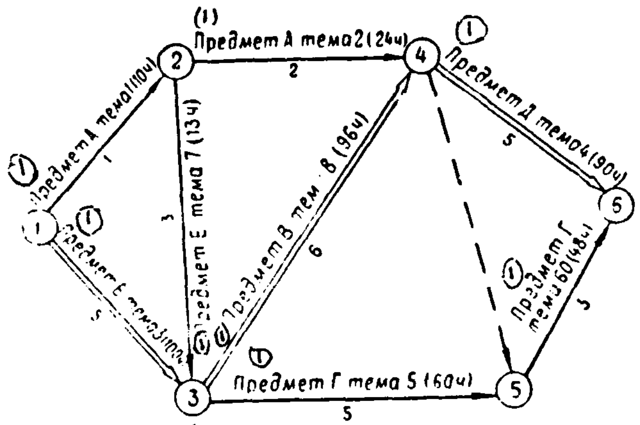

Fig. 56. Initial network graph/curve of combat training of subunit.

Key: (1). Object/subject theme h).

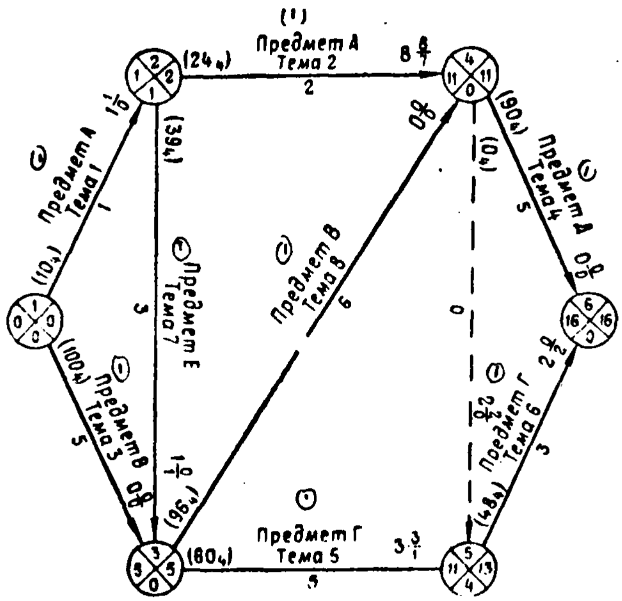

Fig. 57. Designed initial network graph of combat training of subunit.

Key: (1). Object/subject Theme

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In the graph/curve above the arrows/pointers in the brackets is indicated total volume of themes in hours; at the end of the arrows/pointers - general/common/total and local reserves of operating time; under the arrows/pointers - quantity of weeks, during

which must be developed the themes.

Second space. On basis of network graph linear graph/curve (Table 9) is comprised. Graph/curve is constructed as follows. In the graph/count 2 of table the codes of works are written/recorded. In graph/count 3 operating time in the weeks. In graph/count 4 the local reserve of the second type of work is written/recorded. It shows, this work how more lately can be initiated. In our graph/curve the reserve of the second type of each work is expressed by the denominator of the fraction, which stands above of arrows/pointers. These data will be brought in in complex 4 against each work.

Let us agree that during formation of linear graph/curve planned duration of operation $(t_{(i,j)})$ will be deposited by solid line, and quantity/magnitude of local reserve of time by work-points, operating time after optimization-broken line. Work (1, 2) with duration in one week let us apply by solid line in graph/count 5, and above the line let us write volumes of this work, equal to 10 h.

Work (1, 3), which begins simultaneously with work (1, 2) and continues during five weeks, on graph/curve occupies graphs/counts 5-9. In each complex above the solid line is indicated the quantity of hours, which must be developed during each week (100:5-20 h).

All remaining works are depicted thus on graph/curve, in this case they adhere that each subsequent work would be deposited after termination of preceding/previous. For example, work (2, 3) shows since the beginning of the second week, since work (1, 2) preceding it ended at the end of the first week.

Following stage of work on linear graph/curve is determination of total quantity of hours, which is necessary for final adjustment of program during each week, and its comparison with limit of time, tempered to each week on conditions of our problem (30 h to each week). The corresponding total numerals are entered/written in the 10th line of each week.

As can be seen from graph/curve, requirement for resource/service life of time by weeks dissimilar: into 2, 3, 4, 12, 13 and 14th week - more than 30 h, and in 5, 6, 7, 8, 9, 10, 11, 15 and 16th week - less than 30 h. First week 30 h.

Third space. The works, which have local reserves, are examined. This is necessary in order to respectively lengthen the periods of final adjustment of themes and to even intensity/strength by week. Work (1, 2) does not have local reserve, while work (1, 3) is critical and therefore the period of the execution of work is not subject to increase.

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Table 9. Linear graph/curve.

№ по пор. (1)	Код работы (2)	t(i,j)	$P^{*}_{н(i,j)}$	(3) Недели 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	1-2	1	0	10															
2	1-3	5	0	20	20	20	20	20											
3	2-3	3	1		13 / 10	13 / 10	13 / 10	9											
4	2-4	2	8		12	12			4	4	4	4	4	4					
5	3-4	6	0						16	16	16	16	16	16					
6	3-5	5	1						12 / 10	12 / 10	12 / 10	12 / 10	12 / 10	10					
7	4-5	0	0																
8	4-6	5	0												18	18	18	18	18
9	5-6	3	2												16 / 12	16 / 12	16 / 12	12	
10	Общее количество часов в неделю до оптимизации	(4)		30	45	45	33	20	28	28	28	28	28	16	34	34	34	18	18
11	Количество часов в неделю после оптимизации	(5)		30	30	30	30	28	30	30	30	30	30	30	30	30	30	30	18

Key: (1). No on pores. (2). Code of work. (3). Weeks. (4). Total quantity of hours in week before optimization. (5). Quantity of hours in week after optimization.

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Work (2, 3) has reserve one week (5th week), i.e., period of this work can be increased from three weeks to four weeks without risk to increase general/common/total period of execution of curriculum. Then for the final adjustment of the theme of 7 objects/subjects E can be diverted every week on 10 h instead of 13 h. The new distribution of hours the weeks is shown in the 3rd line by dotted line.

Work (2, 4) has reserve of eight weeks. It is not difficult to ascertain that the final adjustment of the theme of 2 objects/subjects A (work 2, 4) must be transferred, since the limit of time into 2, 3, 4 and by the 5th weeks is spent. Before determining concretely/specifically/actually, in what period this theme must be mastered and since hours in the week, it is necessary to examine, how long in the week will engage critical (3, 4) and subcritical (3, 5) works.

Work (3, 4) will engage six weeks on 16 h in week, and it does not have reserve.

Work (3, 5) - final adjustment of theme of 5 objects/subjects G - has local reserve one week. Consequently, the period of the execution of this work can be increased to six weeks on 10 h in the week. The new distribution of hours is emphasized by dotted line.

Then on works (2, 4) and (3, 5) it will be every week spent in the sum of 26 h. In order not to move out the limit of time, devoted in the week (30 h) for the execution of work (2, 4), it is possible to plan 4 h each in the week during six weeks.

And finally, is analyzed work (5, 6), in order to search for capabilities of increase in period of final adjustment of theme 6 of object/subject G, in order not to move out beyond frames/scopes of tempered limit of training hours in week. Work (5, 6) has local reserve two weeks. However, so that our plan/layout would satisfy the established/installed requirements, it suffices to lengthen work (5, 6) only to one week. Then the theme 6 of object/subject G will be mastered during four weeks on 12 h. After optimization a quantity of hours stores/adds up weekly and result is written/recorded in the 11th line.

Thus, producing optimization of network graph, it is possible to attain this position/situation, with which on training will be every week emitted not more than 30 h, i.e., will be achieved uniform training load.

But now for best understanding of order/formation of optimization of network graph let us examine one additional problem in optimization based on specific example. Let us assume that in the

subunit the execution of certain complex of works is charged. Technological sequence/consistency, interconnection and interdependence of these works are depicted on the network graph (Fig. 58). Time, required for execution of each work (see numerals under arrows/pointers), is known, and necessary quantity of personnel, assigned/detailed to these works (see numbers above arrows/pointers). Known also that the subunit can emit to the works not more than on 15 people during the day.

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It is necessary to find the optimum version of the distribution of personnel from the works, which would accomplish the complex of works within the established/installed period with the existing/available human resources/service lives.

By analogy with Table 9 Table 10 is comprised and then optimization of network graph, shown in Fig. 58, is conducted.

As a result of optimization we obtain optimum version of distribution of personnel of subunit from works (Table 10) under condition for execution of entire complex of works within established/installed period.

In conclusion it should be noted that optimization of development for resources/service lives gives valuable information for organizing rhythmic work. With the limited resources/service lives the optimization becomes absolutely necessary. It renders especially great aid during the selection of the optimum version of activities during the solution of the following problems:

- armament in the engineering sense of the defense areas, routes of advance, deployment lines, position areas for different combat means;

- building of bridges, the armament of crossings;

- taking salvage and evacuation measures;

- conducting the decontamination of personnel and radioactive decontamination of equipment;

- maintenance/servicing, repair and the restoration/reduction of combat materiel;

- armament of training and supply base;

- planning combat training;
- organization of the material and technical support of combat operations, etc.

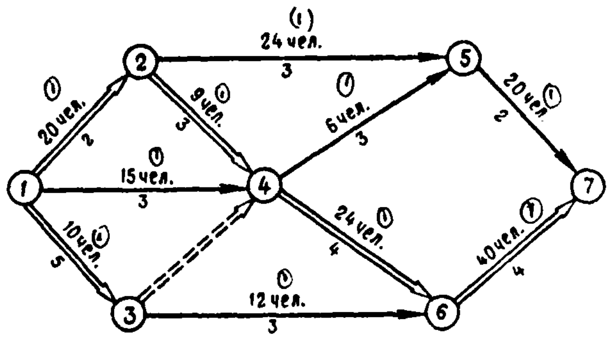

Fig. 58. Network model of the complex of the works of subunit.

Key: (1). man.

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§10. Optimization of network graphs along the flow.

In practice it is necessary so to organize works so that effectiveness of utilized technology (human resources/service lives) would be highest, in other words so that there would be no idle time of personnel and technology due to irrational organization of works.

Definition/determination of optimum sequence/consistency of technologically uniform works by conventional/ordinary methods is difficult problem. At the same time this sequence/consistency can be comparatively easily found on the basis of the analysis of network

graphs from the flow.

Let us examine how this is done based on following simple example. After return from the exercises to four tank subunits of dissimilar personnel/staff/composition and manned by the vehicles/computers of different models it is necessary to conduct maintenance in the volume TO No 2 with the washing of filters. To the works, besides crews, the personnel of repair shop is assigned, and the assemblies and identities/accessory equipment, which are found on PTO, also are utilized.

Table 10.

(1) Код работы	$t_{(i,j)}$	$r''_н$	1	2	3	4	5	6	7	8	9	10	11	12	13
1-2	2	0	10	10											
1-3	5	0	2	2	2	2	2								
1-4	3	2	5 / 3	5 / 3	5 / 3	3	3								
2-4	3	0			3	3	3								
2-5	3	3			8 / 4	8 / 4	8 / 4	4	4	4					
3-4	0	0													
3-6	3	1				4 / 3	4 / 3	4 / 3	3						
4-5	3	0						2	2	2					
4-6	4	0						6	6	6	6				
5-7	2	3									10 / 5	10 / 5	5	5	
6-7	4	0										10	10	10	10
(2) Распределение личного состава по работам до оптимизации			17	17	18	17	16	12	8	8	16	20	10	10	10
(3) Распределение личного состава по работам после оптимизации			15	15	12	15	15	15	15	12	11	15	15	15	10

Key: (1). Code of work. (2). Distribution of personnel from works before optimization. (3). Distribution of personnel from works after optimization.

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Technological sequence/consistency of execution of processes and periods of their execution for each tank subunit are given in Table 11.

It is necessary to determine rational organization of maintenance of tanks on PTO. It is necessary so to plan servicing tanks so that the personnel of repair shop and the assemblies (identities/accessory equipment), which are found on PTO, would be utilized effectively, without idle time, in the flow mode/conditions.

Such missions are accomplished also properly on spaces.

First space. The network graphs of servicing technology for each subunit individually are constructed, in this case it is assumed that all processes are achieved in parallel, simultaneously and independently of each other without the constraint/limitation on the resources/service lives. Are introduced two supplementary events: initial and completing - and they are connected with the graphs/curves by fictitious communications/connections. As a result single network graph (Fig. 59) is obtained.

Second space. The early periods of the termination of works are determined. For this they use the formula

$$t_{\text{р. о}(i,\,j)} = t_{\text{р. н}(i,\,j)} + t_{(i,\,j)}.$$

Then early periods of termination of works for first process will be following:

$$t_{\text{р. о}(1,\,2)} = 0 + 0{,}8 = 0{,}8;$$
$$t_{\text{р. о}(7,\,8)} = 0 + 0{,}5 = 0{,}5;$$
$$t_{\text{р. о}(13,\,14)} = 0 + 0{,}5 = 0{,}5;$$
$$t_{\text{р. о}(19,\,20)} = 0 + 1 = 1.$$

Early periods of termination of works for remaining processes are determined thus and are written/recorded obtained results above the appropriate events (Fig. 59).

Duration is summarized for sectors of works and it is established that critical path passes through IV sector of works [on works, connected with maintenance/servicing of 4th subunit] and it is equal to 12.5 h.

Table 11.

(1) Последовательность процессов	(2) Процессы работы	(3) Время выполнения процессов работы для подразделений, ч			
		1	2	3	4
1	(4) Заправка танков горючим . .	0,8	0,5	0,5	1
2	(5) Внутренняя очистка машин	0,7	0,3	0,5	1
3	(6) Мойка	2,5	1	1,5	3,5
4	(7) Промывка фильтров	2	1	1,5	3
5	(8) Регулировочные работы . . .	3	1,5	2	4

Key: (1). Sequence/consistency of processes. (2). Processes of work. (3). Time of execution of processes of work for subunits, h. (4). Refueling tanks with. (5). Internal cleaning/purification of vehicles/computers. (6). Washing. (7). Washing of filters. (8). Regulating works.

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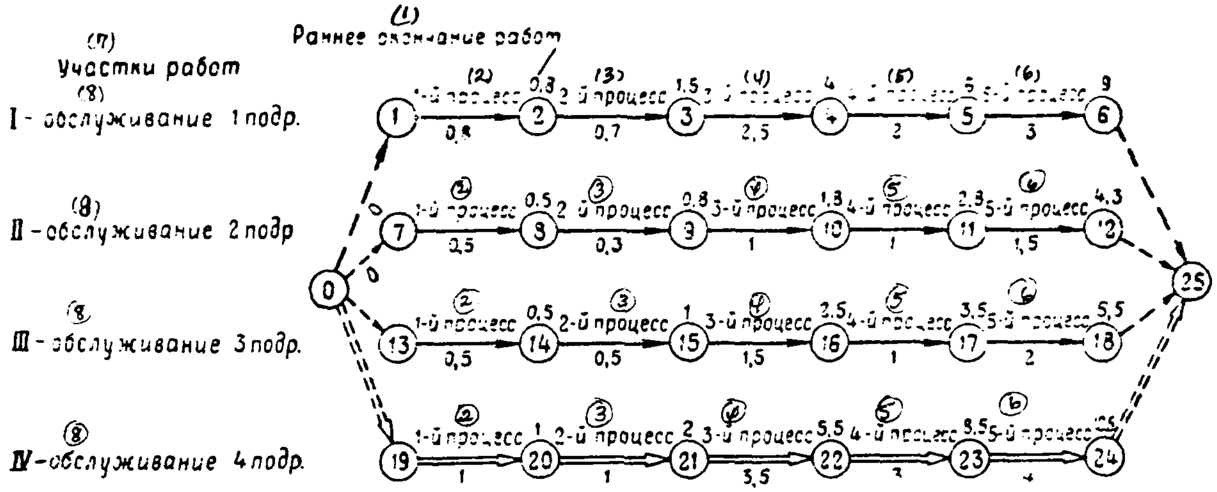

Fig. 59. Summary network chart of maintenance of four tank subunits after return from exercises.

Key: (1). Early termination of works. (2). 1st process. (3). 2nd process. (4). 3rd process. (5). 4th process. (6). 5th process. (7). Sectors of works. (8). Servicing subunits.

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Remaining routes/paths have smaller length:

$$t_{(L_1)} = 9; \; t_{(L_2)} = 4{,}3; \; t_{(L_3)} = 5{,}5.$$

Third space. Sequence for the sectors of works is determined, i.e., it is determined, in what sequence it is expedient to service subunits. For this purpose is comprised the auxiliary table, in which the early periods of the termination of works are arranged/located along the processes in the ascending order of their absolute value (Table 12).

Analyzing data of Table 12, it is possible to establish that in majority of processes sequence of maintenance/servicing is following: II sector, III sector, I sector, IV sector. This sequence let us accept for all processes as single. Then the brigades of repair shop, created for the execution of the specific processes, must first of all service the combat vehicles of the 2nd subunit, then the 3rd and 1st and finally 4th subunit.

Fourth space. They begin the formation of the production lines and the formation of new network graph. In this case the established/installed sequence/consistency of servicing technology is considered.

Composing graph/curve, it is necessary to follow logic of formation, which consists of following (Fig. 60).

1st process in III sector can be begun after its termination in II sector, and beginning of this process in I sector will be after termination on III sector, etc.

Table 12.

Процессы работы	Ранние сроки окончания работ
1-й процесс	0,5 (II участок); 0,5 (III участок); 0,8 (I участок); 1 (IV участок)
2-й процесс	0,8 (II участок); 1 (III участок); 1,5 (I участок); 2 (IV участок)
3-й процесс	1,8 (II участок); 2,5 (III участок); 4 (I участок); 5,5 (IV участок)
4-й процесс	2,8 (II участок); 3,5 (III участок); 6 (I участок); 8,5 (IV участок)
5-й процесс	4,3 (II участок); 5,5 (III участок); 9 (I участок); 12,5 (IV участок)

Key: (1). Processes of work. (2). Early periods of termination of works. (3). process. (4). sector.

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Therefore on the schedule of operation (1, 2) (2, 3) (3, 4) (4, 12) are depicted as consecutively/serially made. the 2nd process in the II sector can be initiated after the end of the 1st process. Consequently, event (2) is initial event for work (2, 5), which reflects this process. The 2nd process in the III sector is stipulated/agreed upon/caused not only end of the 2nd process in the II sector (internal cleaning/purification of the tanks of the 2nd subunit), but also by end of the 1st process in the III sector

(servicing the tanks of the 3rd subunit).

In other words, internal cleaning/purification of tanks of 3rd subunit with the aid of assemblies, which are located on point/post of internal cleaning/purification PTO, can be initiated after servicing of tanks of 3rd subunit and after 2nd subunit will free appropriate assemblies.

It would seem, for display/representation of these conditions it suffices to connect events (5) and (3) by fictitious communications/connection and to designate 2nd process in III sector by work (3, 7), but then it will be obtained that execution of 1st process in I sector (servicing tanks of 1st subunit) depends on end of 2nd process in II sector (internal cleaning/purification of tanks of 2nd subunit). But this does not correspond to reality. Therefore for the correct image of the interconnection of the work of this unit and their real sequence/consistency supplementary event (6), which is connected by fictitious communications/connections with events (3) and (5), is introduced.

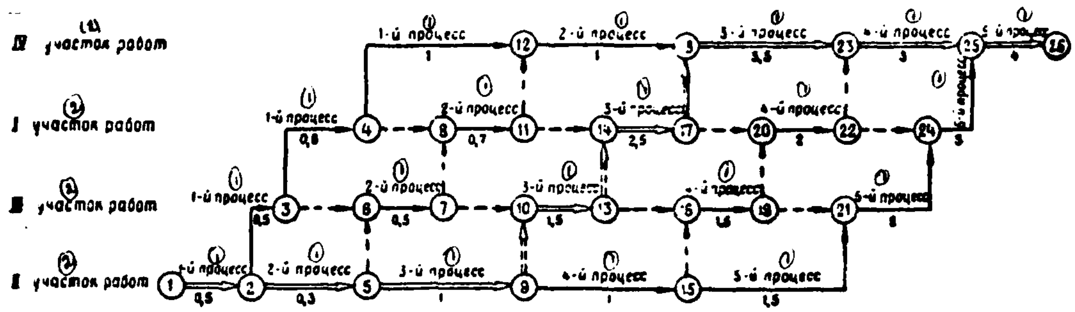

Fig. 60. Network graph, constructed according to the production lines.

Key: (1). process. (2). sector of works.

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Dependence for events (8), (10), (14), (16), (20) and for beginning of works (8, 11), (10, 13), (14, 17), (20, 22) analogously is indicated.

As a result will be obtained network graph, which is shown in Fig. 60.

Fifth space. The parameters of network graph are calculated. The calculation/crew of the parameters of network graph can be conducted

employing the described procedure by graph or tabular method.

Results of calculation/crew of network graph by tabular method are given in Table 13.

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Table 13.

(1) Количество предшествующих работ	(2) Код работ	(3) Продолжительность работ	(4) Наиболее раннее время		(7) Наиболее позднее время		(8) Общий резерв времени	(9) [illegible]
			(5) начала	(6) окончания	(5) начала	(6) окончания		
1	2	3	4	5	6	7	8	9
0	1—2	0,5	0	0,5	0	0,5	0	0
1	2—3	0,5	0,5	1	0,8	1,3	0,3	0
1	2—5	0,3	0,5	0,8	0,5	0,8	0	0
1	3—4	0,8	1	1,8	1,8	2,6	0,8	0
1	3—6	0	1	1	1,3	1,3	0,3	0
1	4—8	0	1,8	1,8	2,6	2,6	0,8	0
1	4—12	1	1,8	2,8	3,8	4,8	2	0
1	5—6	0	0,8	0,8	1,3	1,3	0,5	0,2
1	5—9	1	0,8	1,8	0,8	1,8	0	0
2	6—7	0,5	1	1,5	1,3	1,8	0,3	0
1	7—8	0	1,5	1,5	2,6	2,6	1,1	0,3
1	7—10	0	1,5	1,5	1,8	1,8	0,3	0,3
2	8—11	0,7	1,8	2,5	2,6	3,3	0,8	0
1	9—10	0	1,8	1,8	1,8	1,8	0	0
1	9—15	1	1,8	2,8	4,8	5,8	3	0

Table 13 continued.

1	2	3	4	5	6	7	8	9
2	10–13	1,5	1,8	3,3	1,8	3,3	0	0
1	11–12	0	2,5	2,5	1,8	4,8	2,3	0,3
1	11–14	0	2,5	2,5	3,3	3,3	0,8	0,8
2	12–18	1	2,8	3,8	4,8	5,8	2	2
1	13–14	0	3,3	3,3	3,3	3,3	0	0
1	13–16	0	3,3	3,3	6,3	6,3	3	0
2	14–17	2,5	3,3	5,8	3,8	5,8	0	0
1	15–16	0	2,8	2,8	5,8	5,8	3,5	0,5
1	15–21	1,5	2,8	4,3	5,8	7,3	3	0,5
2	16–19	1,5	3,3	4,8	5,8	7,3	2,5	0
1	17–18	0	5,8	5,8	5,8	5,8	0	0
1	17–20	0	5,8	5,8	7,3	7,3	1,5	0
2	18–23	3,5	5,8	9,3	5,8	9,3	0	0
1	19–20	0	4,8	4,8	7,3	7,3	2,5	1
1	19–21	0	4,8	4,8	7,3	7,3	2,5	0
2	20–22	2	5,8	7,8	7,3	9,3	1,5	0
2	21–24	2	4,8	6,8	7,3	9,3	2,5	1,0
1	22–23	0	7,8	7,8	9,3	9,3	1,5	1,5
1	22–24	0	7,8	7,8	9,3	9,3	1,5	0
2	23–25	3	9,3	12,3	9,3	12,3	0	0
2	24–25	3	7,8	10,8	9,3	12,3	1,5	1,5
2	25–26	4	12,3	16,3	12,3	16,3	0	0
	26–к		16,3		16,3			

Key: (1). Number of previous works. (2). Code of works. (3). Operating time. (4). Most early time. (5). beginning. (6). termination. (7). Most late time. (8). General reserve of time. (9). Local reserve of time of second form.

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From Table 13 it is evident that critical path passes through events (1), (2), (5), (9), (10), (13), (14), (17), (18), (23), (25), (26) and $t_{\text{кр}}$=16.3 h.

Sixth space. Checking is conducted, are there no gaps/breaches/bursts in the processes. For this on basis of network graph linear graph/curve on the early beginnings of works (Table 14) is constructed. Analyzing graph/curve, we are convinced, that in the 2nd process between works (2, 5) and (6, 7); (6, 7) and (8, 11); (8, 11) and (12, 18) there are organizational gaps/breaches/bursts of the small duration, which are respectively equal to 0.2; 0.3; 0.3 h. Let us designate these gaps/breaches/bursts by indices $R_{o\,II,\,III}$, $R_{o\,III,\,V}$, $R_{o\,I,\,IV}$, where roman numerals of the number of the sectors, between which there is a gap/breach/burst.

Gaps/breaches/bursts of larger duration are in two latter/last

processes. In the 4th process three gaps/breaches/bursts by duration 0.5; 1 and 1.5 h and in the 5th process three gaps/breaches/bursts by duration 0.5; 1.0 and 1.5 h. These gaps/breaches/bursts attest to the fact that personnel of repair shop, assemblies and mechanisms of PTO, which facilitate servicing technology, are utilized irrationally. They are applied noncontinuously, with outages, i.e., they, after servicing one subunit, stay in the waiting of the capability to begin the maintenance/servicing of another subunit. This is especially evident at the 4th process. The brigade of the repair shop, which is occupied by the washing of filters on the equipped stands, after completing the task (9, 15) (washing of the filters of the 2nd subunit), is forced for 0.5 h to await, until it will be possible to begin the washing of the filters of the 3rd subunit. However, after fulfilling work (16, 19), brigade is newly forced to make on 1 h an interruption. The same duration organizational gap/breach/burst is observed also between works (20, 22) and (23, 25).

Such idle times in use of personnel and complicated armament testify about poor organization of labor/work.

However, what is it necessary to do in order to improve organization of labor/work in these processes and to attain this position/situation, with which personnel of workshop and assemblies PTO would be utilized continuously in flow regime?

Further work on graph/curve will help to remove these deficiencies/lacks. Let us make the following spaces.

Seventh space. A comparative analysis of quantitative indices/measures of organizational gaps/breaches/bursts with the general/common/total and local reserves of the time of the previous works is conducted. These indices/measures are characterized by following data.

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In 2nd process:

- first gap/breach/burst between works (2, 5) and (6, 7):

$$R_{o\,II,\,III} = 0{,}2;$$
$$P_{n\,(2,\,5)} = 0;$$
$$P^{*}_{n\,(2,\,5)} = 0;$$

- second gap/breach/burst between works (6, 7) and (8, 11):

$$R_{o\,III,\,I} = 0{,}3;$$
$$P_{n\,(6,\,7)} = 0{,}3;$$
$$P^{*}_{n\,(6,\,7)} = 0;$$

- third gap/breach/burst between works (8, 11) and (12, 18):

$$R_{o\,I,\,IV} = 0{,}3;$$
$$P_{n\,(8,\,11)} = 0{,}8;$$
$$P^{*}_{n\,(8,\,11)} = 0.$$

In fourth process:

- first gap/breach/burst between works (9, 15) and (16, 19):

$$R_{o\,II,\,III} = 0{,}5;$$
$$P_{\text{п}\,(9,\,15)} = 3;$$
$$P^{*}_{\text{п}\,(9,\,15)} = 0;$$

- second gap/breach/burst between works (16, 19) and (20, 22):

$$R_{o\,III,\,I} = 1{,}0;$$
$$P_{\text{п}\,(16,\,19)} = 2{,}5;$$
$$P^{*}_{\text{п}\,(16,\,19)} = 0;$$

- third gap/breach/burst between works (20, 22) and (23, 25):

$$R_{o\,I,\,IV} = 1{,}5;$$
$$P_{\text{п}\,(20,\,22)} = 1{,}5;$$
$$P^{*}_{\text{п}\,(20,\,22)} = 0.$$

In fifth process:

- first gap/breach/burst between works (15, 21) and (21, 24):

$$R_{o\,II,\,III} = 0{,}5;$$
$$P_{\text{п}\,(15,\,21)} = 3;$$
$$P^{*}_{\text{п}\,(15,\,21)} = 0{,}5;$$

- second gap/breach/burst between works (21, 24) and (24, 25):

$$R_{o\,III,\,I} = 1{,}0;$$
$$P_{\text{п}\,(21,\,24)} = 2{,}5;$$
$$P^{*}_{\text{п}\,(21,\,24)} = 1{,}0;$$

- third gap/breach/burst between works (24, 25) and (25, 26);

$$R_{o\,I,\,IV} = 1{,}5;$$
$$P_{\text{п}\,(24,\,25)} = 1{,}5;$$
$$P^{*}_{\text{п}\,(24,\,25)} = 1{,}5.$$

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Organizational gap/breach/burst ($R_о$) can be determined according to linear graph/curve, and also from table of calculation/crew of parameters of network graph according to formula

$$R_о = t_{р.\,н\,(j,\,k)} - t_{р.\,о\,(i,\,j)}.$$

For example, it is necessary to determine organizational gap/breach/burst between works (9, 15) and (16, 19) with the aid of Tables 13 and 14:

$$R_{о\,\mathrm{II},\,\mathrm{III}} = t_{р.\,н\,(16,\,19)} - t_{р.\,о\,(9,\,15)} = 3{,}3 - 2{,}8 = 0{,}5.$$

All obtained indices/measures are written/recorded on linear graph/curve in the manner that it is shown in table 14.

After fulfilling this work, they begin improvement in graph/curve for the purpose of obtaining flow. For this the capability of the optimization of process along the flow at first is determined. This capability is set to the following dependences:

$$R_о = P_{п\,(i,\,j)};$$
$$R_о = P'_{п\,(i,\,j)};$$
$$P_{п\,(i,\,j)} > R_о > P'_{п\,(i,\,j)}.$$

i.e., to optimize it is possible due to the reserves of operating time (general/common/total or quotient).

If organizational gap/breach/burst in its quantity/magnitude exceeds general reserve of operating time, then it is not possible to optimize process along flow, without lengthening general/common/total period of execution of entire complex of works. The first gap/breach/burst of the 2nd process clearly illustrates this case.

Actually/really, organizational gap/breach/burst between works (2, 5) and (6, 7) is equal to: $R_{o\,II,III}$ - 0.2, and general/common/total and local reserves of operating time (2, 5) they are equal to 0, i.e., this work lies/rests on critical path. Consequently, there is no capability whatever to pass from the early ones to the late periods of beginning and termination of the works (the critical work has the early and late periods of beginning and termination of works they are equal to each other).

Hence it follows that 2nd process is not subject to optimization along flow.

If we attempt to nevertheless make 2nd process flow, then period of execution of entire complex of works would be lengthened on 0.8 h $(R_{\text{o II, III}} + R_{\text{o III, I}} + R_{\text{o I, IV}}$ = 0.2+0.3+0.3).

Let us examine 4th process for the purpose of its optimization along flow. From Table 14 it is evident that this process can be made flow, since:

$$P_{n\,(9,\,15)} > R_{\text{o II, III}} > P^{*}_{n\,(9,\,15)}\,(3 > 0{,}5 > 0);$$
$$P_{n\,(16,\,19)} > R_{\text{o III, I}} > P^{*}_{n\,(16,\,19)}\,(2{,}5 > 1{,}0 > 0);$$
$$P_{n\,(20,\,22)} = R_{\text{o I, IV}} > P^{*}_{n\,(20,\,22)}\,(1{,}5 = 1{,}5 > 0).$$

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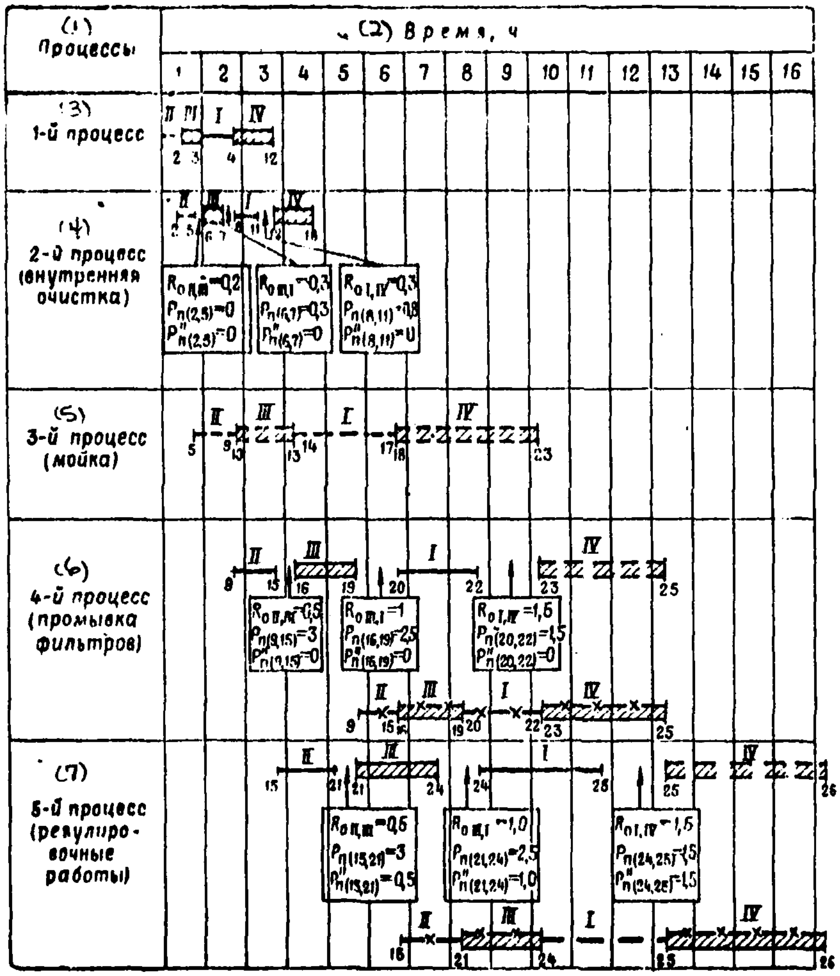
Table 14.



The conventional designations.

R_0. Organizational gap/breach/burst processes.

$R_{0\,II,III}$ Organizational gap/breach/burst between II and III sectors.

$_1$——$_2$ Work (1.2).

$\rho_{n(2,5)}$ Total/full/complete reserve for work (2.5).

$\rho''_{n(2,5)}$ Local reserve of second form of work (2.5).

— — — Works, which lie on critical path.

—×—×— Optimized works.

Key: (1). Processes. (2). Time, h. (3). process. (4). 2nd process (internal cleaning/purification). (5). 3rd process (washing). (6). 4th process (washing of filters). (7). 5th process (regulating works).

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In interests of reaching/achievement of continuity of work in 4th process they more precisely formulate graph/curve, beginning from its end.

Third gap/breach/burst is equal to 1.5 h.

Since work (20, 22) has general reserve $P_{n(20,22)}$=1.5 it is possible to move its periods of beginning and termination to quantity/magnitude of gap/breach/burst, without risking to increase period of offensive of terminal event.

Discussing analogously, are shifted/sheared periods of carrying out of works (16, 19) and (9, 15), striving continuity in gang work on washing of filters.

By the same method due to transition/transfer from early periods to late periods of beginning and termination of works (24, 25), (21, 24) and (15, 21) is provided organization of flow, also, in 5th process.

So is optimized network graph along flow and is achieved rational organization for use of personnel of repair shop, and also assemblies and identities/accessory equipment of PTO on servicing of technology.

If according to first graph/curve (before optimization) brigade

of repair shop for washing of filters took up work for 1.8 h after beginning of servicing vehicles/computers, then according to new graph/curve this brigade can begin work for 4.8 h. And this will in no way influence the established/installed period of the termination of the complex of works on servicing of all vehicles/computers.

Furthermore, according to original plan repair team in course of execution of works on washing of filters of all tank subunits forced was to lose 3 h of time on downtime. Now this time can utilize personnel of repair shop for other works.

Given example to optimization of network graph along flow clearly shows that described procedure is good instrument for achievement of rational organization of elaborate complex of works, in course of realization of which simple qualified personnel, technology and armament it is eliminated.

Methods of optimization of net/system presented along flow can be used also for deciding/solving other operational-tactical and technical tasks/missions.

For the purpose of best mastering of question of optimization of network graph let us examine one additional example.

To staff/headquarters of subunit organization of exercises on demonstration of armament and combat materiel for four groups of training different specialities is charged. Each group can carry out materiel inspection simultaneously only at one training place. Is known the determined by senior commander sequence/consistency of the arrival of groups to the first training place. With the examination/inspection of group technique they must not spend time on the waiting of queue/line.

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Time of examination/inspection of technology at each training place for each group is different, and it is shown in Table 15.

It is necessary to determine optimum version of examination/inspection of combat materiel and armament with all groups, with which would be spent minimum quantity of time. Analyzing the process of the examination/inspection of technology at three training places, we will obtain the graph/curve, which is shown in Fig. 61. Optimizing this graph/curve for the purpose of an improvement in the flow of examination/inspection, we will obtain the new network graph (Fig. 62).

Table 15.

(1) Группа	(2) Время осмотра техники, находящейся на учебных местах, ч		
	№ 1	№ 2	№ 3
1-я	2	1	1
2-я	0,5	1	2
3-я	0,5	2	0,5
4-я	0,5	1	0,5

Key: (1). Group. (2). Time of examination/inspection of technology, which is located on training places, h.

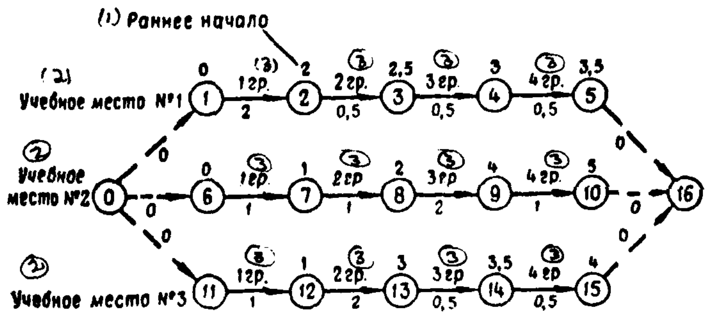

Fig. 61. Initial network graph of demonstration of armament and combat.

Key: (1). Pan- beginning. (2). Training place. (3). gr.

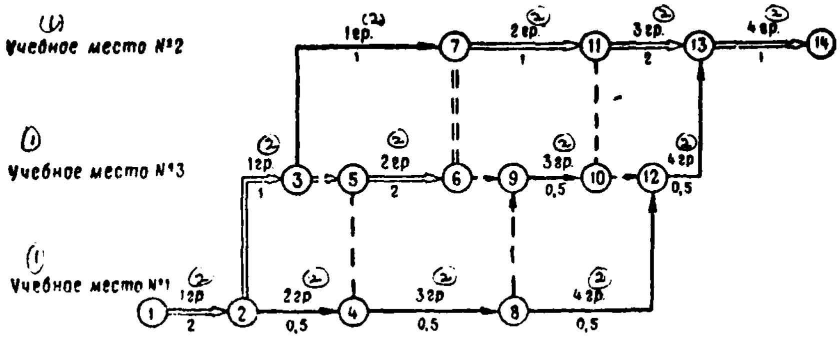

Fig. 62. Optimized network graph of demonstration of armament and combat materiel along production line.

Key: (1). Training place. (2). gr.

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Data of calculation/crew of parameters of network graph are cited in Table 16.

On the basis of ascending order of early termination of works sequence of examination/inspection of technology will be following: training place No1, training place No 3, training place No 2.

Process of optimization of network model flow is shown on linear graph/curve (Table 17).

Table 16.

(1) Количество предшествующих работ	(2) Код работ	$t_{(i,j)}$	$t_{р.н(i,j)}$	$t_{р.о(i,j)}$	$t_{п.н(i,j)}$	$t_{п.о(i,j)}$	$R_{п(i,j)}$	$R^{*}_{п(i,j)}$
0	1—2	2	0	2	0	2	0	0
1	2—3	1	2	3	2	3	0	0
1	2—4	0,5	2	2,5	2,5	3	0,5	0
1	3—5	0	3	3	3	3	0	0
1	3—7	1	3	4	4	5	1	1
1	4—5	0	2,5	2,5	3	3	0,5	0,5
1	4—8	0,5	2,5	3	5	5,5	2,5	0
2	5—6	2	3	5	3	5	0	0
1	6—7	0	5	5	5	5	0	0
1	6—9	0	5	5	5,5	5,5	0,5	0
2	7—11	1	5	6	5	6	0	0
1	8—9	0	3	3	5,5	5,5	2,5	2
1	8—12	0,5	3	3,5	7	7,5	4	2
2	9—10	0,5	5	5,5	5,5	6	0,5	0
1	10—11	0	5,5	5,5	6	6	0,5	0,5
1	10—12	0	5,5	5,5	7,5	7,5	2	0
2	11—13	2	6	8	6	8	0	0
2	12—13	0,5	5,5	6	7,5	8	2	2
2	13—14	1	8	9	8	9	0	0

Key: (1). Number of previous works. (2). Code of works.

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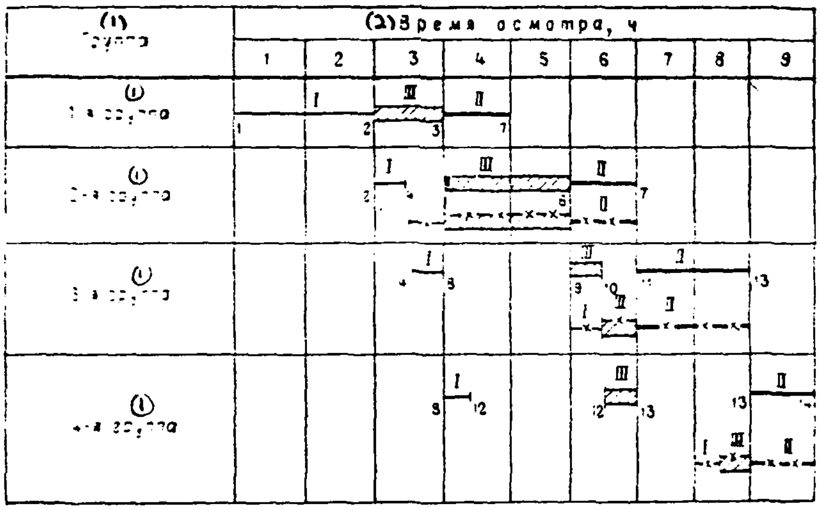
Thus, we were introduced to methods of optimization of network graphs, with the aid of which duration of operations/processes was changed, resources/service lives were distributed or flows were determined, which in complicated processes can give reliable guarantee of observance of outlined periods.

Table 17.



The conventional designations. training of place No 1. training of place No 2. training of place No 3. the optimized flow.

Key: (1). Group. (2). Time of examination/inspection, h.

2. Transition/transfer to the calendar periods and the formation of scale network graphs.

After network graph is designed and optimized, it is necessary to reduce it to form, convenient for control of planned/glide process (operation/process). For this purpose network graph is tied to the calendar periods.

Depending on planned/glide process, its duration, and also on specific conditions, under which process will be realized, in principle can be used two methods of survey of designed and optimized graph/curve to concrete/specific/actual calendar periods: survey with the aid of time scales and survey with the aid of scale network graph.

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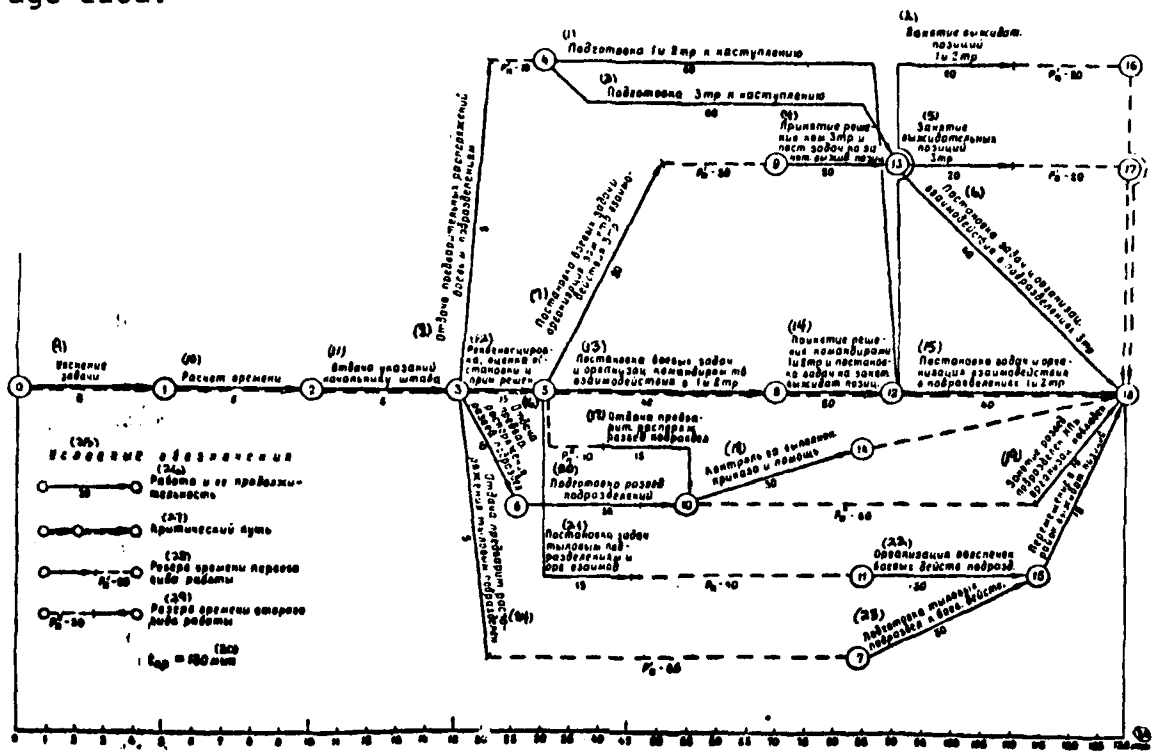

Fig. 63. Scale network graph of training tank battalion for offensive.

Key: (1). Training of 1 and 2 tank company (tr) to offensive. (2). Taking of expectant positions 1 and 2 tr. (3). Training of 3 tr to offensive. (4). Decision making of com. of 3 tr and posing of problems on occupying of expectant positions. (5). Taking expectant positions 3 tr. (6). Posing of problems and organization of cooperation in subdivisions 3 tr. (7). Formulation/assignment of

combat problems and organization of substitute/deputy of ktb of cooperation 3 tr. (8). Issuing preliminary instructions to combat subunits. (9). Understanding problem. (10). Timing. (11). Issuing of instructions to commander/chief of staff. (12). Reconnaissance, estimate of situation and making decision. (13). Formulation/assignment of combat tasks/missions and organization by commander of tank brigade (tb) of cooperation into 1 and 2 tr. (14). Acceptance of command decision 1 and 2 tr and formulation of problems on occupying expectant positions. (15). Formulation of problems and organization of cooperation in subunits 1 and 2 tr. (16). Issuing preliminary instruction to reconnaissance subsection. (17). Issuing of preliminary instruction to reconnaissance subsection. (18). Monitoring/checking of performed order and aid. (19). Exercise of reconnaissance subdivision of observation post (NP) and organization of observations. (20). Preparation of reconnaissance subunits. (21). Formulation of problems to rear subunits and org of cooperation. (22). Organization of provided combat actions of subdiv. (23). Preparation of rear subsections for combat. action. (24). Issuing of preliminary instruction to rear subdiv. (25). Conventional designations. (26). Work and its duration. (27). critical path. (28). Reserve of time of first type of work. (29). Reserve of time of second type of work. (30). min.

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Survey to calendar periods with the aid of time scales can be used during planning of prolonged processes (combat operations). This can be during planning of the building of military objectives and structures/installations, training process, process of production, repair and reduction of combat materiel, large/coarse developments, etc.

Since designed and optimized graph/curve has general/common/total duration in specific units of time, for survey to concrete/specific/actual calendar periods are constructed two time scales one above another. On the upper scale the natural series of numbers from one to the number, which indicates the end of the planned/glide process, is entered/written. This upper number/series is nothing else but the quantity of units of time, required for the accomplishment of entire process. In lower number/series calendar periods (calendar days of months minus of leave days and holidays) are entered/written, if process occurs in peacetime.

Let, for example, be given planned by network method process of major repair of group of combat vehicles, designed on 21 days. The process of repairing this group begins with 16 Nov. 1966.

Table 18 gives survey of designed graph/curve to calendar dates.

In upper scale Table 18 are written estimated periods, in lower - calendar dates with exclusion of output and holidays.

Survey to calendar periods with the aid of scale network graph is advisable during planning of combat activity of troops/forces and all forms of combat, material and technical support. This survey gives the capability to utilize a scale network graph as operational document for the formulation of the problems to the troops/forces, the organizations of cooperation and all forms of support/security/provision, and also for the leadership/manual of the planned/glide process in the course of combat operations.

Let us examine scale network graph and principles of its formation.

Scale network graph (Fig. 63) is finally designed and optimized network graph, transposed to scale time scale. The formation of this graph/curve is the very useful stage of work, and in many instances and to necessary, since scale network graph gives demonstrative representation about the course of the process according to the time.

Table 18.

(1) Расчетные сроки . .	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
(2) Календарные даты	16.11	17	15	19	21	22	23	24	25	26	28	29	30	1.12	2	3	6	7	8	9	10

Key: (1). Estimated periods. (2). Calendar dates.

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With the aid of this graph/curve it is possible to see entire planned/glide operation/process (process) on the time in that technological sequence/consistency, in which must be developed this operation/process (process). In fact, scale network graph reflects the process of the cooperation of the participating in the operation/process (process) forces and means/facilities on the problems, the targets and the time and therefore it appears as the schedule of cooperation.

Besides this, scale network graph can serve seemingly operational document, on which it is possible to pose completely substantiated and, consequently, also objective problems to subunits and units, which participate in combat (process). Together with this, having scale network graph, it is possible to control/guide process, utilizing internal resources/service lives and reserves of time,

since scale network graph makes it possible to see entire planned/glide battle (process), to see the existing/available internal resources/service lives and reserves and thus to operationally control/guide progress of combat (process). Knowing entire course of combat operations (process) as a whole and existing/available reserves of time and resources/service lives, it is possible to maneuver with these resources/service lives and reserves, striving the accomplishment of all events in the net/system within the planned periods.

Scale network graph gives capability to forecast course of combat operations (process), to foresee possible deflections long before they will occur, and to in a timely manner take measures to their prevention. Scale network graph makes it possible in each concrete/specific/actual situation to accept optimal solutions/decisions.

Thus, scale network graph is reliable instrument of command of troops with accomplishment by them of diverse objectives.

Formation of scale network graph is conducted in following order/formation. On the millimeter graph paper or on the ruled sheet the time scale is plotted/deposited. For one

time it is possible to take seconds, minutes, hours, days, weeks or months. This each time is solved concretely/specifically/actually depending on conditions, and take those units the measurements, which are convenient for the control of process. In Fig. 63 as one the measurements are undertaken minute.

Let us note that for convenience it is frequently expedient to make time scale different-scale. This is necessary so that it would be possible to depict graphically not prolonged on the operating time and to accomodate the designation of the work on the arrow/pointer. In our example (Fig. 63) this so is made/done. From 0 to 15 time on the scale scale is written through each minute, and further to the end the time is written in every 5 min.

After scale scale with the aid of optimized graph/curve and design schedule is constructed, scale graph/curve is traced. Formation begins from the critical path. Work of critical path on the graph/curve are extracted into one line, which determines the length of graph/curve.

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Initial event (in our graph - zero event) is accommodated on zero ordinate in center of graph/curve. From this event entire

net/system is constructed to scale. Taking into account the duration of each operation, they plot/deposit it to scale. Each work concludes with the event, which follows after it.

Events are accommodated by their centers on perpendiculars, restored from time marks of their accomplishment, noted on scale of scales. For example, work (0, 1) concludes with event (1). Duration of this operation 5 min. We find mark with numeral 5 on the scale scale and from this mark we restore perpendicular to the scale of scales. On this perpendicular against the zero event we accommodate event (1), whose center we place on the perpendicular. Zero and first event they are connected by the arrow/pointer, from above which the designation of work is written, and its duration in the minutes from below is entered/written.

Analogously to scale remaining works are constructed. When work occurs at angle to the scale scale, its duration is measured as projection on the scale scale. For example, works (3, 4) and (3, 7) are arranged/located their duration is recliningly, determined by the projections of these works on the scale scale and is equal to 5 min. In this case the events, between which is included the work, should be plotted scale network according to the table of the calculation/crew of the optimized graph/curve, taking into account the local reserves for works. For the formation of our scale network

graph we utilize Table 19, in which is given this calculation/crew.

If work has reserve of time of first form, then work to scale should be plotted/deposited, beginning from initial event. The end of the work should be noted the prime, from which further by dotted line is plotted/deposited the reserve of the time of the first type of this work to the final event. Under the dotted line the quantity/magnitude of this reserve is entered/written. For example, let us enter on the scale network graph (Fig. 63) work (5, 11). We find this work in Table 19 and see that this work has local reserves of the time of the first form, equal to 40 min. The duration of this operation is equal to 15 min. We plot/deposit this work from event (5) to scale. Since the work begins 30 min after the beginning of the work of battalion commander, it will be finished after 45 min. We carry out arrow/pointer (work) until this time and we limit by its prime. Further, by dotted line we plot/deposit local reserves for this work, equal to 40 min, and let us deposit final event (11) of this work, the late time of accomplishment of which is equal to 85 min. Under this dotted line we enter/write the quantity/magnitude of this reserve P'_{n} equal to 40 min.

If work has local reserve of time of second form, they enter/write work, beginning from final event, after depositing it on late time of accomplishment. For example, let us enter on the graph work (10, 18). From Table 19 it is evident that this work has local reserves of the time of the second form, equal to 60 min.

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Table 19. Table of the calculation/crew of the optimized network graph.

(1) События i	j	$t_{р.н(i,j)}$	$t_{(i,j)}$	$t_{р.о(i,j)}$	$t_{п.н(i,j)}$	$t_{(i,j)}$	$t_{п.о(i,j)}$	$r_п$	$r'_п$	$r^{\bullet}_п$
0	1	0	5	5	0	5	5	0	0	0
1	2	5	5	10	5	5	10	0	0	0
2	3	10	5	15	10	5	15	0	0	0
3	4	15	5	20	25	5	30	10	10	0
3	5	15	15	30	15	15	30	0	0	0
3	6	15	10	25	60	10	70	45	45	0
3	7	15	5	20	80	5	85	65	65	0
4	12	20	60	80	30	60	90	10	0	10
4	13	20	60	80	30	60	90	10	0	0
5	8	30	40	70	30	40	70	0	0	0
5	9	30	20	50	50	20	70	20	20	0
5	10	30	15	45	85	15	100	55	55	10
5	11	30	15	45	70	15	85	40	40	0
6	10	25	30	55	70	30	100	45	0	0
7	15	20	30	50	85	30	115	65	0	25
8	12	70	20	90	70	20	90	0	0	0
9	13	50	20	70	70	20	90	20	0	10
10	11	55	30	85	100	30	130	45	15	0
10	18	55	15	70	115	15	130	60	0	60
11	15	45	30	75	85	30	115	40	0	0
12	16	90	20	110	110	20	130	20	20	0
12	18	90	40	130	90	40	130	0	0	0
13	17	80	20	100	110	20	130	30	20	0
13	18	80	40	120	90	40	130	10	0	10
14	18	85	0	85	130	0	130	45	0	45
15	18	75	15	90	115	15	130	40	0	40
16	18	110	0	110	130	0	130	20	0	20
17	18	100	0	100	130	0	130	30	0	30

Note. In Tables 19, 21 and 22 critical works are detailed/assigned with fatty/greasy rules.

Key: (1). Events.

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Let us deposit final event (18) on the late time of its accomplishment, which is equal according to Table 19 130 min. From event (18) we plot/deposit to scale work (10, 18), equal to 15 min, and will note the beginning of this work by prime. Work will be begun 115 min after the beginning of the work of battalion commander and will end after 130 min, after being completed by event (18). Further, from the beginning of this work to event (10) we carry out to scale the dotted line, equal to 60 min, under which we indicate the quantity/magnitude of the reserve of the time of second form P''_n.

If work does not have local reserves of time, then it will be deposited within designed early periods of its beginning and termination. For example, work (6, 10) does not have the local reserves of time; therefore on the scale network graph we plot/deposit it to scale on the early time of beginning and termination.

Having scale network graph, it is possible to see entire process as a whole, to see works and available to them reserves, and also mutual technological and logical communications/connections of time. To this concrete/specific/actual period it is possible to see the course of the process, what works should be begun later, and what earlier than estimated periods. From the graph/curve it is possible to establish/install, from what work, what resources/service lives and to what period must be utilized in order to accelerate entire process as a whole.

Presence of scale network graph will help to distribute works between executors/performers of process. For example, in our graph/curve (Fig. 63) all works, which lie on critical path before event (8), will be made by battalion commander. However, beginning from event (5), basic work on the organization of combat operations and cooperation is conducted already in parallel. For example, work (5, 8) is made by battalion commander, work (5, 9) - his deputy, and work (5, 10) and (5, 11) - chief of the staff/headquarters of battalion. In this case the chief of staff of battalion will begin to make work (5, 11) after the execution of work (5, 10), utilizing a reserve for work (5, 11), equal to 40 min (Table 19).

Network graph is also reliablc instrument during control of process, which will be examined below.

3. Use of methods SPU during the administration by a process.

During optimization of net/system detailed analysis of conditions of course of process is conducted, bottlenecks are determined and methods of their elimination are located. In this case to the maximum degree is utilized the knowledge and experience, which help to find more optimal solutions/decisions. But this yet does not mean that the optimized network graph and corresponding initial data are absolutely precise and that in the process of the execution of works will not be deflections from the selected plan.

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The probability of the appearance of these deflections depends on the presence of the random factors, which affect the execution of works, but they do not always yield to a precise accounting. Therefore it is necessary to operationally control/guide the planned process. In the course of the execution of original plan will have to introduce correction into it.

How does occur control of process with existing traditional method of planning?

In course of execution of works can be formed situation, when in one place all occurs on routine, while in other - delay. Measures to the elimination of this delay are taken, plan/layout is reformed/redisposed. However, under these conditions it cannot be known, what effect this delay will have on the final result of combat operations (development). Works in one place are adjusted by the taken measures, but then delay in the third place, etc appears.

Network methods are effective, they make it possible to be dismantled/selected in course of combat operations or process. After obtaining of information about the condition of works the analysis of the entire net/system is done: the length of new critical path is determined, reserves are computed, the appearing obstacles are revealed/detected and their effect on other works is established/installed. On the basis of the overall situation the methods and means/facilities for their elimination are determined. This makes it possible to lead process with the foresight, to in a timely manner forecast process.

If in developments, where network planning is not applied, observation of process is conducted as if into narrow slot, which makes it possible to examine/scan only small sector of works, then

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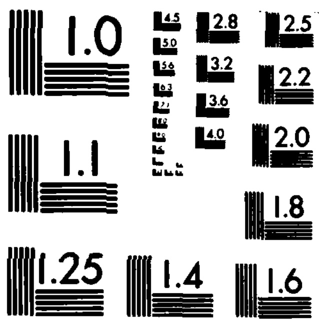

MICROCOPY RESOLUTION TEST CHART
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with network methods is examined/scanned entire elaborate complex of measures in minute detail. Network model makes it possible to scientifically analyze operation and to make the most advisable decisions.

Network planning possesses the advantage that it makes it possible to employ special means and methods, which provide with full-valued information about actual condition of program and prospects for its execution relative to assigned missions, and also it makes it possible to come to light/detect/expose critical sectors in course of execution of process according to one or the other parameters (time, resources/service lives, etc.). This information makes it possible to accept timely and effective solutions by the control of the course of the process.

After final correction of net/system stage of control of process attacks/advances. It begins from the moment/torque of putting net/system into operation and concludes simultaneously with the completion of the complex of works. Target of this stage - reaching/achievement of this position/situation, upon which the final event of network graph began within the given period and within the framework of the detailed/assigned resources/service lives, in spite of possible unforeseen difficulties and deflections within the periods of the execution of the individual works of graph/curve.

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In connection with this problems of planning in course of execution of works are realization of monitoring/checking of actual condition of works, development/detection and analysis of appearing changes, adjustment of plan/layout, redistribution of resources/service lives and compilation every time of new graph/curve of predictions/forecasts.

For successful accomplishment of these objectives network planning provides for number of measures, which ensure continuous observation of operation because of well fixed service of information and reports periodically obtained from responsible executors/performers about course of execution of works, which are located on critical and subcritical paths, and less frequently about remaining works.

Volume of information and its content must be differentiated in connection with different levels of leadership/manual, moreover volume of information must be maximally clear and short. The periodicity of information depends on specific conditions and is determined job superintendent.

Information, transmitted from bottom to top, must contain information not only about condition of going works, but also information about all predicted changes. In the reports the data about the new works and the events, about possible changes in interconnections and topology of nets/systems, about the review of temporary/time estimations/evaluations, about a change in the periods of the isolation/liberation of forces and means/facilities of the materials and other resources/service lives, about the total/full/complete or partial completion of one or the other works can be indicated.

Information on questions indicated must be given in coded form. For the designation of the condition of works it is better to apply the single-valued code. For example:

0 - work fell, it was taken/removed;

1 - supplementary work, introduced again;

2 - work, which goes with the delay (it is not done);

3 - work, which goes according to the plan/layout;

4 - work, which goes in advance;

5 - carried out work.

For transmission of reason for nonfulfillment of works ambiguous system of codes can be utilized. In connection with the control of combat training this system of the codes can be the following:

11 - deficiency/lack in the engine lives;

22 - disengagement of personnel to other works;

33 - unpreparedness of training and supply base;

44 - factor of weather;

88 - other reasons.

For transmission of estimation/evaluation of quality of performed work three-valued codes can be accepted:

101 - work is performed "excellently";

102 - work is performed "good";

103 - work is performed "satisfactorily";

104 - work obtained unsatisfactory estimation/evaluation.

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Each next information must be presented by executors/performers into higher organ/control within strictly established/installed period in the form of card, shown in Table 20.

Card indicated, in fact, is standard document, which contains large quantity of information. At the same time this document can be developed within the very short period and transmitted to command for any communication channels.

In Table 20 they indicate codes: 07 - information is given on fire training; 09 - 3rd tank battalion; 023 - commander of tank battalion. Let work (85, 87) in our example indicate execution by the 7th tank company of the 3rd tank battalion of the training exercise by deposit barrel; numerals 5-103, indicated in the first line of

complex 3, mean that the exercise is performed by this subunit with the estimation/evaluation "satisfactorily".

Work (49, 50) indicates field service firings of tank platoons.

Numeral 2 in second line of complex 3 indicates that work occurs with delay, while numeral 22 in the same complex shows reason for delay (disengagement of personnel to other works). The duration of this operation according to initial graph/curve was equal to 6 days (graph/count 4), and the period of its termination was planned to 10.6 (graph/count 5). However, life introduced its corrections. Responsible executor/performer, after producing calculations/crews taking into account new ones condition, determined, that the operating time will increase to 10 days (graph/count 6), and the period of its performance it is necessary to transfer to 14.6 (graph/count 7).

Work (49, 50) according to initial graph/curve had local reserve of 8 days (graph/count 8). In the new version of local network graph this reserve decreased to 4 days.

On one hand, strict order/formation in representation of reports creates clear rhythm in work.

Table 20.

(1) Шифр раздела боевой подготовки		(2) Шифр части, подразделения, отдела		(3) Шифр ответственного исполнителя	(4) № информации		(5) Дата информации		
07		09		023	10		15.6		
(6) Код работы		(9) Состояние работы	(10) Время работы в сутках	(11) Окончание работы (плановое)	(12) Прогноз		(15) Резерв времени (частный)		(18) Примечание
(7) начало	(8) конец				(13) продолжительность	(14) дата	(16) по плану	(17) оставшийся	
1	2	3	4	5	6	7	8	9	10
85	87	5 101	7	11.6					
49	50	2 22	6	10.6	10	11.6	8	1	...

Key: (1). Cipher of the section of combat training. (2). Cipher of unit, subunit, department. (3). Cipher of responsible executor/performer. (4). No of information. (5). Date of information. (6). Code of work. (7). beginning. (8). end. (9). Condition of work. (10). Operating time a day. (11). Termination of work (planned). (12). Prediction/forecast. (13). Duration. (14). date. (15). Reserve of time (quotient). (16). according to plan/layout. (17). remaining. (18). Note.

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The consideration of job schedule and the estimation/evaluation of their duration disciplines responsible executors/performers, it does not make it possible for them arbitrarily to change the periods of the execution of works or to abolish them. On the other hand, job

superintendent constantly is situated in the course of situation, he sees the sectors of the works, which prove to be under the threat of potential difficulties, which makes it possible for it to in a timely manner take the necessary measures for their overcoming.

After collection of information about operation they begin restoration of network graph. Primary network graph is adjusted by direct executors/performers. Local (local) graphs/curves are more precisely formulated by the leaders of middle link, and compound network by graph-highest link of control. Moreover data processing does not differ from analogous procedure during the compilation of the initial net/system: the calculation/crew of critical path, the definition/determination of the periods of the accomplishment of works and reserves, making/working out/producing recommendations, etc., i.e., is repeated already familiar to us the process of the optimization of net/system.

New network graph is created as a result of restoration of number/series of estimations/evaluations of initial plan/layout. It is, thus, by the collective prediction/forecast of operation at the given moment of time. The analysis of new graph/curve allows, just as in the initial plan/layout, to isolate critical path, to overestimate the reserves of time of the events of the non-critical paths and to evaluate/estimate the probability of the accomplishment of event

within the given period.

One should consider that new network graph can considerably differ from initial optimized graph/curve.

On basis of data, obtained with the aid of new network graph, they are given to recommendation regarding decision making.

Data of analysis of network graph in each stage (after each report) it is expedient to guide to responsible executors/performers so that they would know about their position/situation in general/common/total operation. This moment/torque is new in comparison with the existing methods of the control of the complexes of works.

Under conditions of absence of electronic-computing technology to assembly, processing and information analysis, to making/working out/producing and decision making, apparently, it will be necessary to expend comparatively much time. This circumstance/case/fact thus far limits the sphere of the use/application of network methods in the course of of the control the processes, which have small duration.

Procedure of network planning and control gives capability to

forecast also short-lived processes, changing network model in accordance with predicted conditions, which can running of short-lived process. But this makes it possible to even in the stage of planning provide the necessary measures, if delays in the course of the process occur.

Let us explain this based on following example. Let before the commander and the staff/headquarters of battalion the task of determining optimum version of the incline of subunit on battle alarm/alert stand. To find this decision/solution is possible by the repeated practical incline of subunit by battle alarm/alert.

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But this route/path is too irrational. It requires the high expenditures of material and human resources and time. Therefore it will hardly profitably carry out such experiments. However, utilizing methods SPU, it is possible to use another method of solution of that set problem - this is determination of optimum version by modeling the process of the activities of subunits by the signal "battle alarm/alert". For this on the comprised and optimized network model is produced the drawing of the possible versions of activities by the input/introduction of the most probable delays, short duration failures, deflections from the selected plan.

Losing process of inclining subunit on battle alarm/alert and utilizing methods of SPU, is calculated critical path, they determine reserves of time and plan recommendations for eliminating bottlenecks. These recommendations rest on concrete/specific/actual data, obtained on the basis of scientific analysis.

Determining advisability of applying methods of network planning, it is necessary to consider that basis of successful accomplishment of objectives of control is laid even in period of organization of activities, in period of planning.

Planning/gliding combat operations (process) with use of network methods, commander deeply investigates forthcoming process, he more accurately produces estimation/evaluation of volume and duration of forthcoming operations, gets to know complicated interconnection, logical and technological sequence/consistency of works, determines weak sectors. This gives the capability from entire complex of works and operations/processes to select basic, which determine the general/common/total period of the accomplishment of objective, i.e., work of critical path.

Thus, network methods of planning are allowed for commander,

even who does not have large practical experience, with knowledge of affair to lead process.

Presence of scale network graphs in many respects facilitates control of planned/glide process. Having before itself this graph/curve, commander, knowing the reserves of operating time and delay time, immediately can operationally react/respond to the violation of operation.

Let us turn to Fig. 63 and let us assume that taking expectant positions 1 and 2 tr (work (12, 16)] it is held up on 20 min. After obtaining such data, battalion commander examines/scans all communications/connections in the scale network graph and it establishes, as this delay it will influence the readiness time of tank battalion for the offensive. From the scale network graph (Fig. 63) it is evident that this delay will cause no changes, since the work indicated has reserves of the time of the second form, equal to 20 min.

This analysis shows that in similar situation no measures it is necessary to accept, since this delay as a whole to process of training battalion for offensive will not influence.

During use of computer(s) operational efficiency of control of

process considerably rises. Under these conditions all data of initial plan/layout, and also all past information are stored in the "memory" of vehicle/computer.

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This considerably reduces the flow of operational information and considerably accelerates the solution of the problem by the adjustment of network graph.

Calculations/crews on computer(s) are conducted so rapidly that appears capability to verify effectiveness of decisions/solutions taken by leadership/manual before these decisions/solutions will become directives.

For this purpose data of reports together with proposed decision/solution are introduced in computer(s). The new network graph obtained after processing gives clear representation about the effect of the decision/solution accepted to the final result, including to the capability of appearance of a new critical path.

As a result outlined decision/solution can be either to accepted and acquire force of directive or it is deflected as irrational. In the latter case to leadership/manual are communicated other data for

inspecting/checking the new decisions/solutions until confidence in the accomplishment of final event within the given period is achieved.

Capability "to lose" decisions/solutions should be given also responsible executors/performers, which contributes to search by them effective solutions.

Experience/experiment/lesson of use for calculation/crew of complicated graphs/curves of computer(s) "Minsk-2" convincingly showed advantages of machine count above manual. Payoff/gain in the time is especially noticeable during the correction of net/system, since for each new counting/reckoning/error it suffices to introduce only those data in the computer(s), which are subject to change.

4. Some advice/councils and recommendations regarding the introduction of methods SPU in the troops/forces.

Practical introduction differs from general theoretical considerations in terms of fact that in all cases it is necessary to consider specific character and specific conditions for execution of tasks, for which is applied network graph.

It is necessary to keep in mind that with network methods of

planning is required careful thinking out of sequence/consistency activity, that was not always done with traditional methods, making completely clear, clear and concrete/specific/actual decisions, and not issue of general/common/total instructions, as this is with existing methods. New methods deprive the executors/performers of the capability to explain the disruption/separation of the periods of the execution of works by reference to the different reasons and in advance require the acceptance of concrete/specific/actual measures for the execution of lives.

For successful introduction of network methods of planning and management into practice it is important not only correct to evaluate/estimate value and effectiveness of these methods, but also to strictly observe following basic requirements.

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First, new methods must be introduced in practice so that data of existing methods completely would be utilized, and their results could be compared with results of other methods.

In the second place, transition/transfer to network planning must be realized only on basis of preliminary training of personnel.

Thirdly, in interests of reaching/achievement of maximum effectiveness introduction of new methods must be realized on basis of high organization, discipline of executors/performers and under direct control of leaders.

By important factor, which determines success of use/application of network planning, is correct assimilation all executors/performers of procedure of scheduling network.

To train cadres is possible by independent study of corresponding literature or by enlistment of officers to special assemblies.

Of process of training primary attention must be given to obtaining by officers of skills of work with graphs/curves, ability to independently calculate parameters of nets/systems, development in officers of correct relation/ratio to network graph as to model of complex of operations/processes and, therefore, to more indicative form of plan/layout.

It is necessary to also convince officers of the fact that network planning contributes to clearer coordination of activities of individual executors/performers, it improves organization of works, eliminates simple and decreases number of disruptions/separations in

work. It is important to show trainees that the network methods make it possible to establish/install the clear interconnection of works, which gives complete representation about the prospects for the fulfillment of plan, they help each executor/performer more clearly to see and to understand his role in the general/common/total work. It is useful to also convince officers that the new progressive methods make it possible to total/fuller/more complete consider real capabilities subunit and it is correct to pose to them problems, and to also give initiative to commanders on the places in the development and the realization of measures for the implementation of the outlined program.

After training of officers in bases of network planning it is possible to begin process of introducing network methods.

But does arise question, from what task of beginning?

For beginning it is necessary to drive out/select task (development) simpler so that overcoming difficulties would occur in parallel with gaining of experience. Let this be interesting task in order to entice not only officers and sergeants, occupied in this complex, but also the remaining members of collective.

Desirable also that development would be typical, then

experience/experiment/lesson subsequently will more easily extend. Furthermore, it is necessary to approach that so that the program would be sufficient important so that in the process of optimization it would be more advantageous draw the specialists of others subunit.

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However, let us note that one ought not to inflow into opposite extreme and from the very beginning to start on very difficult development. It is before necessary to master the procedure of network planning, to become accustomed to its special features/peculiarities, and then to introduce in the daily life. For example, it is possible to recommend to compose network graphs on the preparation of subunits for the marching drill review, on the preparation for the execution of firings, on conducting of sport competitions, in preparation for conducting of the demonstration exercises, etc.

Based on these small and simple examples perhaps more graphically is drawn effect of introduction of new methods.

Total/full/complete effect from use/application of network methods should be expected when these methods are applied during planning of large and complicated processes. The more complicated the

complex of the planned works, the greater the effect will be obtained from the use/application of network methods, since in this case to much with more difficulty find correct organizational decision/solution due to a large number of communications/connections between the separate units and the sectors/directions of program. Therefore after officers will master the receptions/methods of work with the small network graphs, it is possible to convert/transfer to the following stage of introduction, to the use of network methods for planning the complicated practical tasks, for example for planning the combat training in the large/coarse staffs/headquarters.

For effective use of new methods of planning with staffs/headquarters perhaps more expedient to create groups of SPU, consisting of 2-4 people. Officers, assigned into these groups, must have high level of training, it is good to know the sequence/consistency of the execution of the outlined works, to the perfection to master the procedure of formation and analysis of network graphs.

Functional responsibilities of this group are determined by stages of introduction.

At preparation stage for introduction of network methods to group can be laid following responsibilities: training officers in

methods of network planning, formulation and multiplication of documents on network planning (standard graphs/curves, forms for transmission of information, etc.).

At stage of planning to group it is expedient to charge: development of block diagram; assembly from responsible executors/performers of primary or particular network graphs; scheduling compound network, its optimization; issue to leadership/manual of necessary data for making of optimum decision; bringing/finishing to information of all interested persons of affirmed network graph.

At stage of control group must be occupied by following: to monitor/control timely representation of information from responsible executors/performers; to analyze, to adjust and to renew network graph; to train/prepare propositions on improvement in plan/layout; to plan measures, directed toward warning/prevention of disruptions/separations of periods of execution of individual works; to inform departments and service of staff/headquarters about course of execution of complex of works; to compose reports for higher headquarters; to accumulate and to analyze statistical data for creation of standard reference base; to develop/process systematic and instructional materials.

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Creation of group of SPU, in our opinion, will not at all humble role and responsibility of corresponding commanders/chiefs for fulfillment of plan. On the contrary, group of SPU must work in the close contact with all services, regularly consult with them, obtain necessary initial data and recommendations from them. In turn group of SPU can lighten the work of different services and departments, since it at any moment can give the necessary information about the course of the execution of program.

Effectiveness of introduction of methods of network planning to a considerable degree depends on correct relation/ratio to these methods of leadership/manual. Commanders must be interested in the assimilation and the practical use/application of new methods, lend constant support in their introduction, in spite of individual possible failures. It is very important so that with network planning commander and chief of staff would be, first of all, sign. With the introduction of network methods in commander (commander/chief) will appear the capability to make decisions on the basis of analysis of objective information, obtained from the network graph and, consequently, also to make the scientifically substantiated decisions.

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CONCLUSION.

Summing up sum presented in labor/work, one should again emphasize that system of network planning and control arose and rapidly it is developed by virtue of objective requirements of life and practice, connected with problems of improvement of methods of planning, analysis of complicated processes and control of them in production, science and military affairs.

Increase in equipment status of armed forces by new weaponry and by different complicated combat and special technology is accompanied/tracked by change not only in conditions, but also character of combat operations. Together with this to the equal degree a quantity grows/rises and become complicated the interdependence between the army organizations of different forms of the armed forces, branches of services and special troops, the conditions for the command of troops become complicated.

In modern combat into staffs/headquarters of different degrees enormous flow of most varied information will enter. From this flow it is necessary in short periods to select and to analyze most

important and necessary, to evaluate/estimate the most important interconnections, to make numerous calculations/crews and to prepare possible decisions/solutions. Therefore without the specially developed, in advance checked and familiar system of planning, analysis and control, being based on wide use electronic-computing technology, this work in a timely manner cannot be fulfilled in effect/virtually. In connection with this of great interest is the system of SPU, which is the effective instrument of planning, analysis and the control. Among other control systems this most multi-purpose, it can be used in the most varied regions of practical activity.

Putting SPU into practice of control can be considered as qualitatively new jump as new development stage of control, which makes it possible to sharply improve control.

System SPU appeared comparatively recently and located now in stage of development and improvement. Newness and insufficient experience/experiment/lesson of the use/application of methods of system somewhat limit thus far their use/application for the solution of the practical problems in military affairs.

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Methods of network planning and control are still inconclusively designed: subjective evaluations are not eliminated and ideal calculations/crews are not provided mathematically. But also in this stage SPU makes it possible to considerably improve the control.

Taking into account successes in improvement and introduction of system, and also prospect for equipment with electronic computers, it is possible to assert, that in the near future majority of tasks in planning and management, research and design tasks in military affairs will be solved with the aid of network methods that these methods will be assumed as basis of automation of number/series of processes in command of troops.

One should expect also that in course of further assimilation and improving of method of SPU and development of electronic-computing technology process of compilation, analysis and optimization of net/system of draft/design/project (development), that requires now even higher expenditure of time and forces, will be automated.

In order to effectively utilize advantage and capabilities of network method of planning and management, it is expedient to prepare wide circle of staff officers and commanders in questions of procedure and principles of network planning and control. It is very

important in this case so that the qualification of officers, who directly carry out network planning, would be highest. These officers must to the perfection know these or other processes analyzed with the aid of the network graphs of combat training or combat activity of the troops/forces.

But if network planning and control is realized in production or in repair subunits, then officers of group SPU must excellently know technology of carrying out ill of repair. These officers also to the perfection must master the methods of formation and analysis of network graphs.

Success of introduction of network methods of planning and controls into practice and effectiveness of their use/application in a decisive/key manner will depend also on knowledge of general principles of system of SPU and interest of officers, who carry responsibility and leaders in each case by other yl those processes.

Network methods of planning and management give great possibilities in questions of objective analysis of processes, in questions of improvement of command of troops. However, this does not mean that the network methods completely reject other, already existing and used in the troops/forces approaches and methods of calculations and analysis, but on the contrary, most effectively they

will be used in communications/connection and in combination with the traditional and checked by practice methods. One should remember that the system of SPU does not free/release commander from the estimation/evaluation of situation and decision making. System only helps on the basis of the objective analysis of situation and foresight to make the most advisable decisions.

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Appendix.

Example of the decision/solution of task "planning of the march of tank battalion" by network method.

Condition of task. The march of tank battalion up to the distance of 125 km is required to plan. For the completion of march three roads of the first class can be used. For retaining/preserving/maintaining the engine lives of tanks the latter are transported on the heavy-duty trailers. March is completed by exercise by the tanks of expectant positions. Devoted on the march time 9 h.

Order/formation of solution of problem. This mission is accomplished in this sequence/consistency:

- is constructed initial network graph;

- is inspected/checked the correctness of the formation of initial network graph;

- are labeled event in the network graph;

- are calculated the parameters of initial network graph and they are compared with the directive ones;

- is optimized initial network graph;

- is constructed the scale network

1. Formation of initial network graph.

Knowing technology of process, we construct initial network graph (Fig. 64) from left to right. In this case above each arrow/pointer (work) we squeak the designation of work, and under arrow - its duration in the minutes.

We do not label event. But if in the initial graph/curve the numbers of events are set themselves, then this is conducted only after the inspection/check of graph/curve to the correctness of formation. The numbering of events is conducted in this case, as stated below.

2. Inspection/check of the correctness of the formation of initial network graph.

Graph/curve is considered constructed correctly, if in it there are no locked ducts/contours or blind events. As can be seen from Fig. 64, in the graph/curve there is neither blind events nor locked ducts/contours. Consequently, graph/curve is constructed correctly.

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3. Numbering of events in the network graph.

Events of initial graph/curve label, if they were not labeled or they renumber them, if they were at first numbered arbitrarily. The numbering of events is conducted by the method of the deletion of arrows/pointers (works), beginning from the initial event (Fig. 64). In this case they enter as follows: delete all works, which come out from the initial event, and appropriate to it zero rank; rank is written/recorded on top above this event; to an event of zero order they appropriate the first number and enter it inside the circle of initial event; to all events, which follow initial event, into which after the deletion of the arrows/pointers, which come out from an event of zero order, enters not one arrow/boom, the first rank is appropriated. In our example from an event of zero order only one work emerges. We cross by its one perpendicular line and we consider

it its crossed out. Then into the following event enters not one work. We appropriate the first rank to it and enter/write it above this event by roman numeral I. We appropriate following reference number 2 to first order event and we write/record with its arabic numeral inside the circle, which indicates first order event.

We further act analogously, moving from left to right and deleting consecutively/serially works by two, three, four, five and so forth by transverse lines. We enter/write the numbers of ranks above the events by roman numerals.

If in net/system several events of one order prove to be, then these events are equal and it is possible to label them consecutively/serially in any order/formation. For example, in Fig. 64 there are three events of the IV order, to which appropriated numbers (5) (6) and (7). The numbers of these events can be interlocked. From this nothing will change.

If events are renumbered according to their rank, then old (arbitrarily undertaken numbers) wipe and instead of them are entered new numbers.

4. Calculation/crew of the parameters of initial network graph and their comparison with the directive ones.

Parameters are calculated by tabular method (Table 21). After calculating the parameters of initial network graph, we see that the length of critical path is equal to 675 min, i.e., 11 h 15 min. This means that with the initial plan/layout of activities accepted by us the battalion will not lie/fall/lay in the directive period, i.e., will not fulfill assigned missions in those diverted to it 9 h. Consequently in order to lie/fall/lay in the directive period, it is necessary to change the original plan of activities, i.e., to improve initial plan/layout. For this purpose we optimize initial graph/curve.

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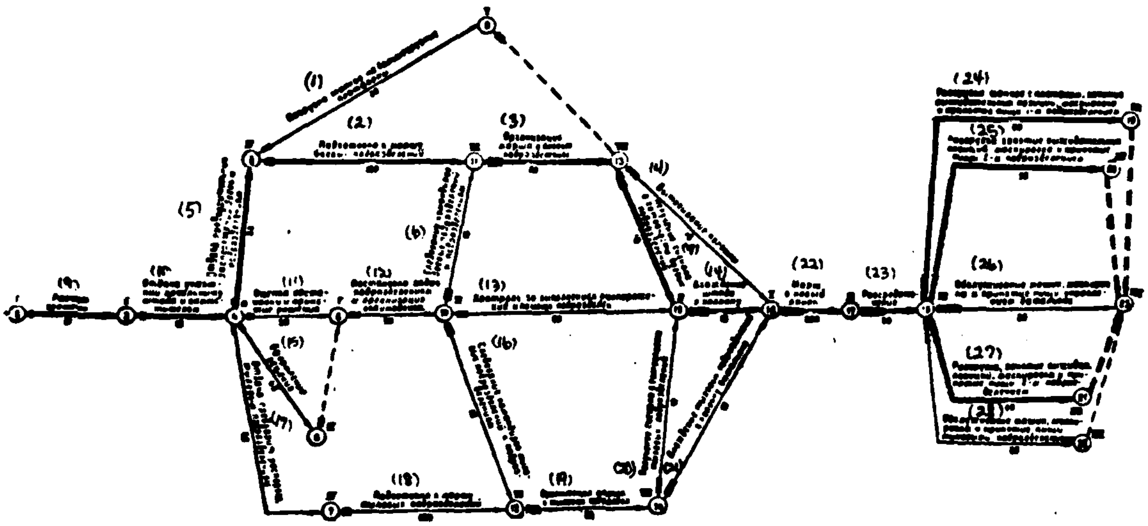

Fig. 64. Initial network graph of march of separate tank battalion.

Key: (1). Loading of tanks to the heavy duty platforms. (2). Preparation/training for march of combat subunits. (3). Organization of march in combat subunits. (4). Drawing column. (5). Issue of warning orders to combat subunits. (6). Sequence of commanders of combat subunits and to subunits. (7). Obtaining signal about readiness of combat subunits. (8). Understanding task. (9). Timing. (10). Issue of instructions to commander/chief of staff and to deputies. (11). Estimate of situation and decision making. (12).

Formulation of problems to subunits and organization of cooperation. (13). Monitoring/checking of execution of instructions and aid is subdivided. (14). Entry of staff/headquarters into column. (15). Formulation of decision/solution. (16). Sequence of commanders of rear subunits to subunits. (17). Issue of preliminary instructions to rear subunits. (18). Preparation/training for march of rear subunits. (19). Organization of march in rear ones subsection. (20). Obtaining signal about readiness of rear subunits. (21). Entry of rear subunits into column of battalion. (22). March into new region. (23). Dispersal. (24). Unloading tanks from platforms, taking expectant positions, camouflage and acceptance of food by 1st subunit. (25). Unloading, taking expectant positions, deception and acceptance of food by 2nd subunit. (26). Servicing vehicles/computers, deception and acceptance of food by control of battalion. (27). Unloading, taking expectant positions, deception and acceptance of food by 3rd subunit. (28). Servicing vehicles/computers, deception and acceptance of food by rear subunits.

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Table 21. Calculation of the initial network graph of the march of separate tank battalion.

(1) Работа		$t_{р.н}(i,j)$	$t(i,j)$	$t_{р.о}(i,j)$	$t_{п.н}(i,j)$	$t(i,j)$	$t_{п.о}(i,j)$	$R_п$	$R'_п$	$R''_п$
(2) начальное событие	(3) конечное событие									
1	2	3	4	5	6	7	8	9	10	11
1	2	0	30	30	0	30	30	0	0	0
2	3	30	10	40	30	10	40	0	0	0
3	4	40	15	55	40	15	55	0	0	0
4	5	55	30	85	55	30	85	0	0	0
4	6	55	45	100	55	45	100	0	0	0
4	7	55	30	85	80	30	110	25	25	0
4	8	55	30	85	70	30	100	25	15	0
5	9	85	30	115	235	30	265	150	150	0
5	11	85	120	205	85	120	205	0	0	0
6	8	85	0	85	100	0	100	15	0	0
7	12	85	120	205	110	120	230	25	0	0
8	10	85	90	175	100	90	190	15	0	0
9	13	115	0	115	265	0	265	150	0	150
10	11	175	15	190	190	15	205	15	0	0
10	12	175	15	190	215	15	230	40	25	15
10	15	175	60	235	215	60	275	40	25	40
11	13	205	60	265	205	60	265	0	0	0
12	14	205	30	235	230	30	265	30	0	0
13	15	265	10	275	265	10	275	0	0	0
13	16	265	15	280	270	15	285	5	5	5
14	15	235	10	245	265	10	275	30	0	30

Table 21 continued.

1	2	3	4	5	6	7	8	9	10	11
14	16	235	10	245	275	10	285	40	10	40
15	16	275	10	285	275	10	285	0	0	0
16	17	285	300	585	285	300	585	0	0	0
17	18	585	30	615	585	30	615	0	0	0
18	19	615	60	675	615	60	675	0	0	0
18	20	615	60	675	615	60	675	0	0	0
18	21	615	60	675	615	60	675	0	0	0
18	22	615	30	645	645	30	675	30	30	0
18	23	615	30	645	645	30	675	30	30	0
19	23	675	0	675	675	0	675	0	0	0
20	23	675	0	675	675	0	675	0	0	0
21	23	675	0	675	675	0	675	0	0	0
22	23	645	0	645	675	0	675	30	0	30

Key: (1). Work. (2). initial event. (3). final event.

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5. Optimization of initial network graph.

Network graph is optimized by reduction of critical path. In our case the net/system is improved due to a change in technology of process, due to the development and the parallel execution of some works. The optimized graph/curve is shown in Fig. 65.

From comparison of initial (Fig. 64) and optimized (Fig. 65) of

network graphs it is easy to establish/install changes, produced in initial (initial) plan/layout of activities. Thus, work (1, 2) of initial graph/curve is separated to two and in the optimized graph/curve is two works - (1, 2) and (2, 4). Work (2, 3) is carried out forward and in the optimized graph/curve begins 10 min after obtaining of task on march, which led to the reduction of critical path on 25 min. Work (3, 4) in the initial graph/curve is abbreviated/reduced, since in the optimized graph/curve the deputy commanders of battalion and chief of staff together with the battalion commander understand task and therefore it suffices to only say to them, who and to whom must issue instructions.

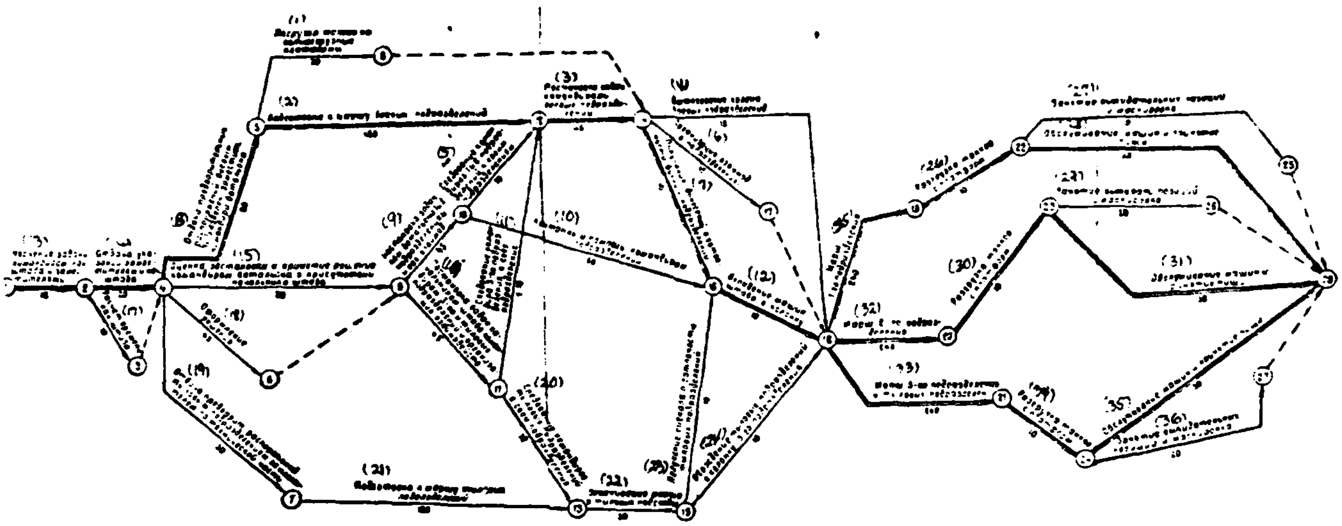

Fig. 65. Optimized graph/curve of the march of separate tank battalion.

Key: (1). Loading tanks to the heavy duty platforms. (2). Preparation/training for march of combat subunits. (3). Formulation of problems by commanders of combat subunits. (4). Drawing of column of combat subunits. (5). Sequence of commanders 1 and 2 subunits to its subunits. (6). Organization mutually-d in subunits. (7).

Obtaining reports about readiness of combat subdivisions. (8). Issue of warning orders to combat subdivisions, deputy battalion commander. (9). Formulation/assignment of tasks of com. of battalion 1 and 2 subunits and org of coop. (10). Monitoring/checking and aid to commanders of subunits. (11). Sequence of commander of 3rd subunit into its subunit. (12). Entry of vehicles/computers of staff/headquarters into column. (13). Understanding task by commander, head of staff/headquarters and by deputies. (14). Issue of instructions to substituents and head of staff/headquarters. (15). Estimate of situation and decision making by commander of battalion in presence of chief of staff. (16). Formulation of problems by chief of staff/headquarters to commanders of 3rd and rear subunits and organization of cooperation. (17). Timing head of staff/headquarters. (18). Formulation of decision. (19). Issue of preliminary instruction to rear subunits by deputy on technical section. (20). Sequence of commanders of rear subunits into its subdivision. (21). Preparation/training for march of rear subunits. (22). Organization of march in rear subsections. (23). Obtaining signal about readiness of rear subunits. (24). Entry of rear subunits into column of 3rd subunit. (25). March of 1st subunit. (26). Unloading tanks from platforms. (27). Taking expectant positions and deception. (28). Servicing vehicles/computers and acceptance of food. (29). Taking expectant positions and deception. (30). Unloading tanks from platforms. (31). Servicing vehicles/computers and acceptance of food.

(32). March of 2nd subunit. (33). March of 3rd subunit and rear is subdivided. (34). Unloading tanks from platforms. (35). Servicing vehicles/computers and acceptance of food. (36). Taking expectant positions and deception.

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The work, which has in the initial graph/curve code (11, 13), is separated and in the optimized graph/curve already two works - (12, 14) and (14, 17). Latter/last work is made in parallel with work (14, 16), due to what critical path is reduced on 15 and more min. Simultaneously work (8, 10) in the initial graph/curve is substituted two works - (9, 10) and (9, 11), which in the optimized graph/curve are made in parallel. The general/common/total duration of these two operations is equal to the duration of operation (8, 10) in the initial network graph.

Works, which have code (16, 17) and (17, 18), in initial graph/curve are separated and in optimized graph/curve already three works - (18, 19) (18, 20) and (18, 21). In the new graph/curve the movement of each subunit along its march route is provided; which makes it possible to increase the rate/velocity of movement and, consequently, also to shorten critical path on 90 min.

Finally, works, which have in initial graph/curve codes (18, 19) (18, 20) and (18, 21), are separated and are made in parallel; in optimized graph/curve they are works (19,22) (22, 25) (22, 28); (20, 23) (23, 26) (23, 28); (21, 24) (24, 27) and (24, 28). This shortened critical path by 20 more min.

After optimization of graph/curve let us calculate its parameters. The calculation/crew of the parameters of network graph is given in Table 22. From Table 23 it is evident that the critical path of the optimized graph/curve is equal to 525 min (8.75 h). Directive period is achieved, and therefore further optimization of graph/curve ceases.

Thus, due to change in technology of process and parallel execution of works it was possible to shorten time of preparation of march and its completion on 150 min and to lie/fall/lay in directive periods.

6. Formation of scale network graph.

Since process of optimization is finished, on basis Table 22 and optimized network graph (Fig. 65) we construct scale network graph, which is shown in Fig. 66. In this graph/curve the route/path from event (18) and to the terminal event branches to three branches.

Dotted lines with the arrows/pointers indicate logical communications/connections or no-load operations. The dotted lines, which are the beginning of continuous arrows or their continuation, designate the respectively particular or general reserves for works. The forms of the reserves of operating time and their quantity/magnitude are written from below the dotted lines and have designations: $P'_n - 5$; $P''_n - 45$ and $P_n - 45$, where P'_n the local reserve of the first form; P''_n the local reserve of the second form; P_n the general reserve for work.

Numerals, which follow after letters, show quantity/magnitude of reserve.

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Table 22. Calculation/crew of the optimized graph/curve of the march of separate tank battalion.

Работа										
начальное событие	конечное событие	$t_{р.н(i,j)}$	$t_{(i,j)}$	$t_{р.о(i,j)}$	$t_{п.н(i,j)}$	$t_{(i,j)}$	$t_{п.о(i,j)}$	$R_п$	$\dot{R}_п$	$^{\cdot}R_п$
1	2	3	4	5	6	7	8	9	10	11
1	2	0	10	10	0	10	10	0	0	0
2	3	10	10	20	20	10	30	10	10	0
2	4	10	20	30	10	20	30	0	0	0
3	4	20	0	20	30	0	30	10	0	10
4	5	30	30	60	30	30	60	0	0	0
4	6	30	45	75	75	45	120	45	45	0
4	7	30	30	60	90	30	120	60	60	0
4	9	30	30	60	90	30	120	60	60	15
5	8	60	30	90	195	30	225	135	135	0
5	12	60	120	180	60	120	180	0	0	0
6	9	75	0	75	120	0	120	45	0	0
7	13	60	120	180	85	120	205	25	0	0
8	14	90	0	90	225	0	225	135	0	135
9	10	75	45	120	120	45	165	45	0	0
9	11	75	45	120	120	45	165	45	0	0
10	12	120	15	135	165	45	180	45	0	0
10	16	120	60	180	175	60	235	55	10	55
11	12	120	15	135	165	15	180	45	25	0
11	13	120	15	135	190	15	205	70	0	45
12	14	180	45	225	180	45	225	0	0	0
13	15	180	30	210	205	30	235	25	0	0

Table 22 continued.

14	16	225	10	235	225	10	235	0	0	0
14	17	225	15	240	230	15	245	5	5	0
14	18	225	15	240	230	15	245	5	5	5
15	16	210	10	220	225	10	235	15	10	15
15	18	210	10	220	235	10	245	25	0	25
16	18	235	10	245	235	10	245	0	0	0
17	18	240	0	240	245	0	245	5	0	5
18	19	245	240	485	245	240	485	0	0	0
18	20	245	240	485	245	240	485	0	0	0
18	21	245	240	485	245	240	485	0	0	0
19	22	485	10	495	485	10	495	0	0	0
20	23	485	10	495	485	10	495	0	0	0
21	24	485	10	495	485	10	495	0	0	0
22	25	495	20	515	505	20	525	10	10	0
22	28	495	30	525	495	30	525	0	0	0
23	26	495	20	515	505	20	525	10	10	0
23	28	495	30	525	495	30	525	0	0	0
24	27	495	20	515	505	20	525	10	10	0
24	28	495	30	525	495	30	525	0	0	0
25	28	515	0	515	525	0	525	10	0	10
26	28	515	0	515	525	0	525	10	0	10
27	28	515	0	515	525	0	525	10	0	10

Key: (1). Work. (2). initial event. (3). final event.

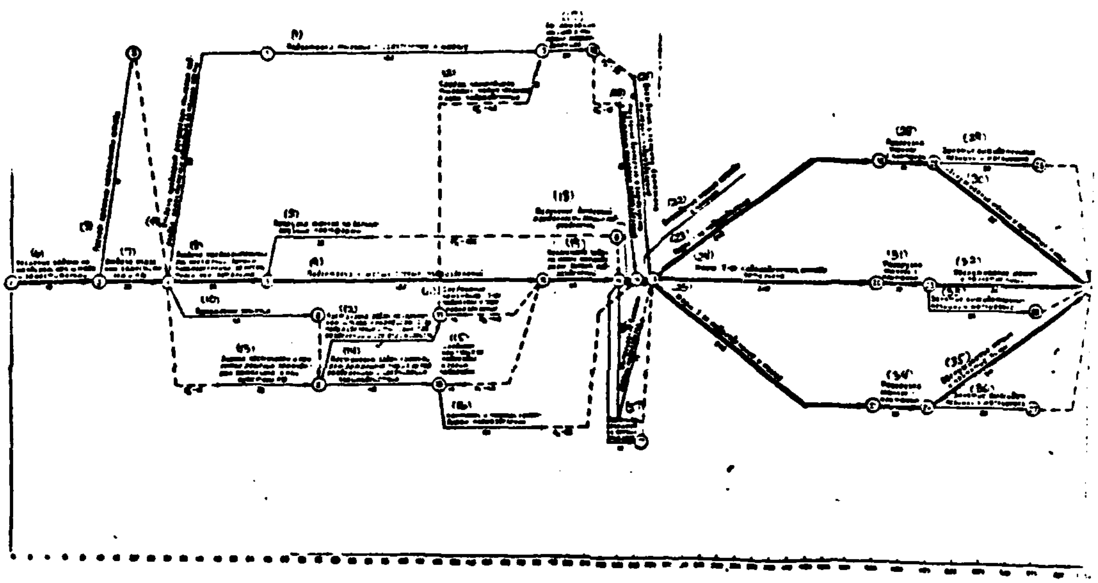

Fig. 66. Scale network graph of march of separate tank battalion.

Key: (1). Preparation of rear subunits to the march. (2). Trails, commanders of rear subunits into its subunits. (3). Timing by commander/chief of staff. (4). Issue of preliminary instruction to rear subsection. by deputy commander for tech. unit. (5). Loading of

tanks to heavy duty platforms. (6). Understanding task by commander, head of staff/headquarters and by deputies. (7). Issue of instructions to deputies and chief of staff. (8). Issuing of preliminary instructions to combat subunits by deputy com. of battalion. (9). Preparation/training for march of combat subunits. (10). Formulation of decision/solution. (11). Sequence of commander 3rd subsection into its subunit. (12). Formulation of problems by chief of staff to commanders of 3rd subunit and rear subunits and org of coop. (13). Estimate of situation and acceptance of command decision of battalion in the presence of chief of staff. (14). Formulation of problems by battalion commander to 1st and 2nd subunits and organization of cooperation. (15). Is followed com. of 1st and 2nd subsection. to its subsection. (16). Monitoring/checking and aid to commanders of subunits. (17). Organization of march in rear subdivisions. (18). Obtaining of reports about readiness of combat subunits. (19). Formulation of problems on march by commanders of combat subunits. (20). Obtaining report about readiness for movement of rear subunits. (21). Entry into column of battalion of rear subunits. (22). Entry of vehicles/computers of staff/headquarters into column. (23). March of 1st subunit. (24). March of 2nd subunit, staff/headquarters of battalion. (25). March of 3rd subunit and rears. (26). Elongation of column of combat subdivisions. (27). Organization of coop. in combat subdiv. (28). Unloading tanks from platforms. (29). Taking expectant positions and

deception. (30). Servicing vehicles/computers and acceptance of food. (31). Unloading tanks from platforms. (32). Servicing vehicles/computers and acceptance of food. (33). Taking expectant positions and deception. (34). Unloading tanks from platforms. (35). Servicing vehicles/computers and acceptance of food. (36). Taking expectant positions and deception.

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